REPORT #
RRTAC 87-7

The Use of Bottom Ash as an Amendment to Sodic Spoil

Heritage Fund

Alberta

LAND CONSERVATION AND RECLAMATION COUNCIL
Reclamation Research Technical Advisory Committee

Report No. RRTAC 87-7

THE USE OF BOTTOM ASH AS AN AMENDMENT TO SODIC SPOIL

by

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Soil Protection Branch

Prepared for

The Reclamation Research Technical Advisory Committee

of

The Land Conservation and Reclamation Council

1987

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

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The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of the Environment and two Deputy Chairmen from the Department of Forestry, Lands & Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

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** 1.	RRTAC 80-3:	The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.
	DESCRIPTION:	This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.
** 2.	RRTAC 80-4:	Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.
	DESCRIPTION:	Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.
** 3.	RRTAC 80-5:	Manual of Plant Species Suitability for Reclamation in Alberta. 2 vols. L.E. Watson, R.W. Parker, and P.F. Polster. 541 pp.
	DESCRIPTION:	Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habitat, propagation, tolerance, and availability information are provided.
N/A 4.	RRTAC 81-2:	1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.
	DESCRIPTION:	This survey is an update of the original report conducted in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.
N/A 5.	RRTAC 81-3:	Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.
	DESCRIPTION:	Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.
N/A 6.	RRTAC 82-1:	Land Surface Reclamation: An International Bibliography. 2 vols. H.P. Sims and C.B. Powter. 292 pp.
	DESCRIPTION:	Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981 are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of recently initiated field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop reproduction.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Technical Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. 2 vols. H.P. Sims, C.B. Powter, and J.A. Campbell. 659 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. 2 vols. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 676 pp.

DESCRIPTION: This is a collection of five reports dealing with reestablishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies. An executive summary outlines the findings.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by

parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establishe a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to suuport post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe, hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

RRTAC Reports 87-1 to 87-6 are in preparation.

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EXECUTIVE SUMMARY

Bottom ash plots were located on sodic mine spoil at the Vesta Mine near Halkirk, Alberta. The mine is situated on the south side of the Battle River, approximately 180 km southeast of Edmonton, in East Central Alberta. The area was mined for coal prior to 1963; at that time there were only provisions for continuous back-filling of areas stripped of overburden to obtain coal. As a result, mined land was left as a series of spoil piles. No topsoil was conserved and the overburden removed was windrowed in the order of extraction.

At the Vesta Mine the overburden topping the coal is a bedrock formation of the late Cretaceous age. Known as the Horseshoe Canyon Formation, this bedrock is a fine-textured non-marine deposit, which is interbedded with bentonitic shales. As a result of mining, the bedrock has been brought to the surface, creating problems in revegetation.

Alberta Environment decided to test bottom ash as a physical amendment to sodic spoil for two reasons. Firstly, preliminary results of a study done at Forestburg South (Shaneman and Logan 1978) indicated that bottom ash could be used to promote revegetation of sodic spoil. Secondly, ash was readily available from a coal-fired thermal generating station nearby.

The objectives of the study were to determine the best rate and method of application of bottom ash to sodic spoil in terms of reducing the effects of excess sodium and promoting vegetative growth. The plots were set up as a randomized complete block design. Each plot measured 10 m by 20 m and was separated from neighboring plots by a 2 m buffer zone. In addition, there were three replicates consisting of 12 plots each. Each replicate was separated by a 10 m buffer zone.

The three rates of bottom ash tested were 10, 20, and 30 cm. Ash was applied to the spoil surface using a D8 crawler tractor and was incorporated using a disc, chisel plow, and Kellough Subsoiler. As a fourth method, ash was left as a blanket on top of the spoil.

Soil samples were taken each year in 15 cm increments to a maximum depth of 90 cm. Measurements for yield were also taken from each plot. Soil moisture was measured on a monthly basis in 15 cm increments

from the spoil surface to a depth of 120 cm using a neutron probe. In 1985, soil strength measurements were taken using a recording soil penetrometer.

Soil samples were analyzed for pH, electrical conductivity (EC), saturation percentage (sat.%), soluble calcium (Ca), magnesium (Mg), sodium (Na) and sulfate (SO_4), percent organic matter (%OM) and boron (B). Plant samples were analyzed for percent nitrogen (N), phosphorous (P), potassium (K), Ca, Mg, and B.

Rate was the most important factor affecting the variables monitored at the plots. Of the three rates tested (10, 20, and 30 cm) the 30 cm rate was the most effective in reducing the effects of excess Na and promoting growth. The 10 cm rate was the least effective. A rate of 30 cm of bottom ash applied to sodic spoil improved the chemistry of the surface 15 cm of the spoil material by decreasing values for pH, sat.%, SAR, and Na_2SO_4. It also increased values for %OM and yield. This rate caused the greatest downwards shift in moisture which promoted the leaching of salts. The 30 cm rate also resulted in the lowest soil strength values. The 10 and 20 cm rates produced yields lower than those reported from local farms, while the 30 cm rate produced higher yields.

Of the four methods tested (disc, chisel plow, subsoiler and blanket) subsoiling was the most effective at reducing the effects of excess Na. Use of the disc produced the poorest results. The subsoiler resulted in the best spoil-ash mix within the surface 30cm of the plots which decreased the sat.%. It also created the lowest soil strength values. Method had no significant effects on any of the plant variables tested.

All of the methods, and the 20 and 30 cm application rates produced plant available B concentrations which were at toxic levels in the soil (Gupta et al. 1985). The soil concentrations were never reflected in any plant toxicity symptoms.

Based on the results of this research, the best way to amend sodic spoil using bottom ash would be to cover the spoil with bottom ash to a depth of 30 cm, then incorporate it using a subsoiler.

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ABSTRACT

The purpose of this project was to test the use of bottom ash as a physical amendment to sodic spoil. The sodic spoil was located at the Vesta Mine near the town of Halkirk in East Central Alberta. The objectives of the study were to determine the best rate and method of application of bottom ash to sodic spoil in terms of reducing the effects of excess sodium and promoting vegetative growth.

The plots were set up as a randomized complete block design. The three depths of bottom ash tested were 10, 20, and 30 cm. Ash was applied to the spoil surface using a D8 crawler tractor and was incorporated using a disc, chisel plow, and Kellough subsoiler. As a fourth method, ash was left as a blanket on top of the spoil.

Each year the plot soils were sampled in 15 cm increments to a maximum depth of 90 cm. Soil moisture was measured in 15 cm increments to a depth of 120 cm. Both yield and soil strength measurements were also collected. Soil variables monitored over the three year period (1983 to 1985) included pH, electrical conductivity, saturation percentage, soluble calcium, magnesium, sodium and sulfate, organic matter, and boron. Plant variables monitored included percent nitrogen, phosphorous, potassium, calcium, magnesium, and boron.

Results showed the best rate of ash to be 30 cm and the best method of incorporation to be subsoiling. Both increased moisture movement downwards and decreased soil strength values which promoted leaching, germination and root growth. The 30 cm rate also improved the chemistry of the surface 15 cm of the spoil and increased yield. Yields using 10 and 20 cm rates were below those reported by local landowners, while yields using 30 cm were higher.

All the methods plus the 20 and 30 cm rates produced toxic levels of plant available boron in the soil. The soil concentrations were not reflected in any plant toxicity symptoms.

ACKNOWLEDGEMENTS

Many thanks are extended to Mr. L. Kryviak and Mr. H. Regier for support throughout this investigation. Special thanks are given to Ms. M. Couture whose exceptional technical aid over the years, made this project possible. Appreciation is expressed to Mr. P. Minarik and Mr. T. Entz for thoroughness in all statistical evaluations. Many thanks are extended to Ms. H. Wilkenson and Ms. D. Stewart for assistance in moisture monitoring. The typing expertise provided by Mrs. B. Lundstad and Mrs. L. Kearl was invaluable in the preparation of this manuscript. Appreciation is extended to Manalta Coal Ltd. for providing services for plot construction and road maintenance, and Mr. D. Haberle for associated farm services. This research was managed by the Research Management Division of Alberta Environment and funded through the Heritage Savings Trust Fund. The program is administered by the Alberta Land Conservation and Reclamation Council through the Reclamation Research Technical Advisory Committee.

1. INTRODUCTION

Since the passing of the Land Surface Conservation and Reclamation Act in 1973, reclamation activities have been undertaken in areas mined and abandoned before 1963 when there were few reclamation regulations. One area requiring information regarding reclamation was that of sodic mine spoil. Hence, reclamation plots were initiated in 1981 on mine spoil at the Vesta Mine near Halkirk, Alberta.

At the Vesta Mine the overburden contains bedrock from the Horseshoe Canyon Formation, a fine-textured non-marine deposit whose prevailing constituent is bentonite. As a result of mining, the bedrock has been brought to the surface creating problems in revegetation. Large amounts of sodium in the spoil causes clay dispersion, resulting in low water infiltration, and poor aeration and drainage. The combination of bentonite and high concentrations of sodium produces material which is very hard when dry and a sticky mass when wet. The material is impermeable to water and roots, and is subject to erosion and extreme shrink-swell pressures.

Bottom ash was chosen as a physical amendment to the spoil at the Vesta Mine for two reasons. Firstly, preliminary results of a study done by Shaneman and Logan (1978) indicated that bottom ash could be used to promote revegetation of sodic spoil. Secondly, ash was readily available from a coal-fired thermal generating station nearby.

Objectives of the study were to determine the best rate and method of application of bottom ash to sodic spoil in terms of reducing the effects of excess sodium and promoting vegetative growth.

2. LITERATURE REVIEW

2.1 BOTTOM ASH

A major by-product of coal-fired thermal generating stations is coal ash, which is the result of the presence of non-combustible mineral matter in coal. Coal ash comprises from 5 to 20% of the composite weight of coal. It is divided into two types according to the nature of the thermal plant operation: bottom ash which is flushed from the base of dry bottom boilers, and fly ash, which is recovered from flue gas electrostatic precipitators. Bottom ash accounts for 20 to 30% of the coal ash produced by thermal units (Shaneman and Logan 1978).

The nature of bottom ash is influenced by a number of factors. These include the nature of the parent material, type and fineness of the coal, and the method of processing (furnace conditions, collection methods, storage methods, and pollution or collection control additives). Since the majority of power plants burn pulverized coal in suspension-fired furnaces, the major sources of variation in the ash come from the type of coal, storage methods, and pollution/collection control additives (Joshi 1981).

In general, there are two methods of handling bottom ash in Western Canada. First is a lagoon or "wet system", which transports the ash as a slurry to surface disposal areas. The second is a "dry system", whereby the ash is transported by conveyor to ash plant silos.

Once bottom ash is collected from thermal power plants, it must be disposed of or stored. Disposal methods include transporting the ash to a dump site, depositing the ash in abandoned mine sites or valleys, or sluicing it into ponds (Joshi 1981).

2.1.1 Mineralogical Properties

More than 75% of the mineral matter in coal consists of clays, pyrite, and calcite. Clays in the form of kaolinite or montmorillonite are reported to form up to 60%, while pyrite and calcite account for 20 and 15% respectively. The remainder of the mineral matter is a mixture of trace minerals (Joshi 1981).

When coal is in the flame zone of a furnace, the fine mineral particles melt. As a result, the minerals undergo physical and chemical changes in the presence of excess air. For example, pyrite is converted into oxides of iron, including spherical particles of magnetite; clay forms glass spheres of complex silicates and mullite as well as some quartz; and calcite is transformed into calcium oxide, calcium hydroxide, calcium silicate and calcium sulfate. Gases are also trapped in some particles giving rise to ceno-spheres, which float on water and are, therefore, also called floaters. The exact nature of changes in mineral particles, which occur in the flame zone, is not completely understood. However, the nature of resultant products depends on various factors such as the type of coal, fineness of pulverized coal, and the particle retention period within the hot zone of the furnace (Joshi 1981).

Bottom ash is produced by sintering of particles. The sintered and molten ash particles fall to the bottom of the furnace, where they are removed and sluiced into lagoons.

2.1.2 Chemical Properties

A number of studies (Lutwick et al. 1981; McCoy et al. 1981; Shaneman and Logan 1978) have examined the various chemical components of bottom ash. Table 1 lists some of the chemical properties of bottom ash from Alberta as determined by three different studies. In general, the ash is moderately alkaline (pH 8.4), non-saline (EC 0.6 mS/cm), has a moderately high saturation percentage (73%), and is non-sodic (SAR 1.3).

Predominant water soluble cations and anions in bottom ash extracts from Alberta are calcium (Ca), magnesium (Mg), sodium (Na), and sulfate (SO_4), bicarbonate (HCO_3), carbonate (CO_3), and boron (B) (McCoy et al. 1981). The range of boron is from 3 to 13 ppm (McCoy et al. 1981).

An interesting phenomenon of bottom ash is its variability. McCoy et al. (1981) found differences between bottom ash samples from different sites, samples from the same site, and a number of samples of one type of bottom ash from a given site.

Table 1. Chemical properties of bottom ash from various power plants in Alberta.

Property	Battle River[a]	Sundance[b]	Battle River[c]	Mean[d]
pH	8.2	8.7	8.3	8.4
EC (mS/cm)	0.5	0.6	0.8	0.6
Sat.%	-	78.0	68.0	73.0
Na (me/L)	1.8	1.8	2.5	2.0
Ca + Mg (me/L)	3.2	4.9	7.8	5.3
SAR	-	1.2	1.3	1.3

[a] McCoy et al. 1981
[b] Lutwick et al. 1981
[c] Shaneman and Logan 1978
[d] Mean values from the three papers referenced.

2.1.3 Physical Properties

The process by which bottom ash is formed affects the color of the particles, which varies from light grey to dark brown. The particles are generally crystalline with glass inclusions, are shiny, and are of sand size (Joshi 1981).

The high sand fraction in bottom ash produces a loose sandy loam texture and a variable but rapid permeability. The pumice-like nature of the ash results in a high saturation percentage and therefore indicates good moisture retention properties (Shaneman and Logan 1978). It has a low solubility and is, in general, non-reactive (Joshi 1981). Bottom ash has an average bulk density of 1.0 g/cc and a hydraulic conductivity of 152.7 cm/hr (Shaneman and Logan 1978).

2.2 SODIC SPOIL

The term sodic is applied to a soil containing sufficient sodium to interfere with the growth of most crop plants, and having an exchangeable sodium percentage (ESP) of 15 or more (Canada Department of Agriculture 1976). Other parameters associated with sodic material include an electrical conductivity (EC) less than 4 mS/cm at 25^{o}C, and a pH between 8.5 and 10 (Richards 1954).

Sodic material is a dispersed soil system where clay-sized soil particles tend to repel one another, permitting each particle to act independently of the other. As a result, poor physical soil conditions are created. Dispersed soils are muddy, plastic-like and sticky when wet, and hard and impermeable when dry. Such soils have low hydraulic conductivities and severely reduced infiltration, particularly if a surface crust forms. The soil is extremely difficult to break into aggregates, and when dry is impervious to water and air movement, and root growth.

The severity of all the problems associated with sodic materials is increased by the presence of large amounts of montmorillonite clay. Not only is sodium adsorption enhanced but the effect of swelling and subsequent dispersion of clay units is magnified.

Serious soil erosion can occur in soils with such unfavorable structure. Low infiltration and hydraulic conductivity may cause surface ponding resulting in the loss of large quantities of soil and water through runoff. Piping erosion is a common occurrence on sodic mine spoil and is thought to develop as a result of deep surface cracks providing a pathway through which water can move (Gee et al. 1978).

In general, the high sodium clays or sodic spoil materials present problems such as impermeability to water, making the exchange and leaching of sodium nearly impossible, and crusting on the soil surface inhibiting seedling emergence, and inducing surface runoff, and accelerated erosion (Brocke 1976).

There are a number of ways to approach the reclamation of sodic spoil. Improving soil structure and thereby increasing water permeability and root penetration may be accomplished by chemical and physical methods. Increasing the amount of soil water for leaching and improving drainage may also permit reclamation of unfavorable sodic material. Cropping and management practices that reduce evaporation and improve the soil tilth may also be applied to mine reclamation in its later stages (Fyles 1982).

2.2.1 Chemical Amendments

Reclamation of sodic spoil involves the replacement of a certain portion of the sodium on the exchange complex with divalent cations. One group of possible amendments is calcium sources such as gypsum and calcium chloride.

Gypsum ($CaSO_4.2H_2O$) is the most commonly used chemical in the reclamation of soils adversely affected by sodium. The usefulness of gypsum is limited by its low solubility in water, particularly if the EC of the soil is greater than 2 mS/cm and sulphate ions are predominant (Henry Regier, personal communication, Alberta Environment, Lethbridge, Alberta). As well, solubility decreases at pH values greater than nine (White and de Jong 1975). Therefore, large quantities of water must be added to spoil amended with this chemical to affect complete dissolution. Since the hydraulic conductivity of sodic materials is often very low, this also implies a considerable time requirement for reclamation (Hadas 1973).

Without physical incorporation the effectiveness of gypsum may be restricted to the top few centimeters of the soil due to low hydraulic conductivity of the subsurface layer. Even after incorporation, a sudden rain may cause crust formation if insufficient time has elapsed for solubilization (Fyles 1982).

Calcium chloride ($CaCl_2$) is a very soluble chemical and produces a leaching solution of high electrolyte concentration. Such a solution increases water intake into sodic spoil and is efficient in replacing sodium in soils with high sodium adsorption ratio (SAR) values (Prather et al. 1978).

Alperovitch and Shainberg (1973) found that flow rates through sodic material depended on the concentration of $CaCl_2$ in the applied solution, and that the higher the concentration of $CaCl_2$, the higher the flow rate. Treatments using $CaCl_2$ were most efficient in leaching excess salts and replacing sodium when concentrated in a small volume of solution. Results indicated that with increasing concentrations of the $CaCl_2$ solution, the affinity of the soil for calcium increased and was responsible for the high efficiency in replacing adsorbed sodium from the soil.

The addition of $CaCl_2$ to sodic material by either surface placement or in a solution is superior to the incorporation of the material into the soil (Magdoff and Bresler 1973). If $CaCl_2$ is scarce but water plentiful, then a solution treatment is the most practical reclamation procedure. If on the other hand, water is scarce and the $CaCl_2$ salt plentiful, then top placement is the most practical reclamation procedure.

Fertilizers have no direct effect on the improvement of sodic material but they may correct the unbalanced nutrient status usually associated with high levels of sodium (Richards 1954). By promoting plant growth they increase the beneficial effects of organic matter and plant roots (Fyles 1982).

The use of chemical amendments in the reclamation of sodic mine spoil is often considered secondary because low precipitation results in a slow rate of chemical reaction and reduces subsequent beneficial effects (ARS and NDSU Staff 1977). However, the use of a combination of chemical and physical amendments may lead to a greater success.

2.2.2 Physical Amendments

The addition of organic matter (manure, sewage sludge, straw, etc.) to sodic soil improves the structure and promotes water movement. Organic matter interacts with the inorganic material and tends to reduce swelling and dispersion of clay. It may also serve as an energy source for microorganisms which in turn can promote stable aggregation of soil particles (Bower et al. 1951). The beneficial effects of organic matter were noted by Harron (1979) in his work on sodic soils. He observed that for similar SAR values, the hydraulic conductivities in A horizon samples were considerably higher than in B horizon samples. He attributed these results to the lower organic matter content and higher clay content in the subsoil.

If plants can be established on sodic materials, they improve the soil tilth through growth and decomposition. Roots add organic materials to the soil thus enhancing soil structure, and open channels which permit percolation of water into the soil. By removing water throughout the rooting zone, they reduce the upward movement of salts. Some deep rooted plants may even lower the water table (White and de Jong 1975). Plants may also reduce evaporation from the soil surface though shading (Luken 1962).

Topsoiling is the most commonly used method of reclamation of sodic mine spoil. Legislation in the United States requires that original soil material be removed and stockpiled before mining, and replaced on mine spoils after reshaping (Power et al. 1978). Current guidelines for agricultural areas in Alberta state that the selective salvage of topsoil and subsoil and subsequent sequential replacement is commonly practised (Alberta Agriculture 1987). Both depth and specific chemical and physical properties are used to determine the suitability of soil material for replacement.

The determination of thickness requirements for materials placed over sodic spoil must make allowances for the upward migration of sodium from spoil into topsoil, the physical characteristics of the spoil, settling and subsidence, surface erosion, and uneven spreading of soil.

Numerous field trials have demonstrated the effectiveness of leaching through irrigation as being an effective way to remove exchangeable sodium from the plant root zone. Reeve et al. (1984) found

that gypsiferrous, saline-sodic soils were reclaimed by leaching with 1.2 m of water. Heald et al. (1950) found that leaching promotes the germination of sugar beets and increases yields in saline conditions. Spoil materials which are fine textured and sodic will have slow water infiltration rates and high water holding capacities. Consequently, the moisture that enters the spoil material will usually be retained in the upper few centimeters and will be lost by evaporation. Leaching will progress at a very slow rate, especially in arid areas. In areas of higher precipitation, sodic spoil may eventually be reclaimed (Sandoval and Gould 1978).

2.2.3 Bottom Ash Amendments

There is some discrepancy in terms of using bottom ash as a calcium source in the reclamation of sodic spoil. Parker (1981) stated that the relatively large amounts of calcium found in bottom ash were considered to be useful as an amendment to sodic spoil. Shaneman and Logan (1978) reported that a 15 cm blanket of bottom ash contained exchangeable calcium approximately equivalent to a 20 tonne/ha application of gypsum. By contrast, McCoy et al. (1981) concluded that bottom ash had little or no potential use as an ameliorative source of calcium in slightly sodic soils, or as a low grade liming material.

Shaneman and Logan (1978) found that a surface 4 to 15 cm application of bottom ash to sodic spoil promoted forage growth. The bottom ash greatly improved the penetration of water, air and roots, and eliminated surface crusting. The authors felt that the loose, coarse textured properties of the ash, combined with the excellent moisture holding properties, were largely responsible for the success of the plots.

Results of a study done by Lutwick et al. (1981) showed that bottom ash had more potential to amend the chemical and physical properties of acidic soils than of alkaline soils. Bottom ash was also found to increase plant available boron, decrease surface crusting, increase water infiltration and increase soil salinity on both solonetzic soils and sodic mine spoil materials.

Webster and Trlica (1977) found that bottom ash had deleterious effects on the growth of western wheatgrass, favoring saltbush and blue

grama grass when it was incorporated into a rangeland soil. High pH, lack of adequate plant nutrients such as nitrates and potassium, and unfavourable structural characteristics of the bottom ash may have caused the reductions in plant growth.

Boron toxicity in plants is often associated with bottom ash amended spoil in greenhouse studies, as the ash contains extractable boron in quantities which are normally toxic to plants. Barley grown in bottom ash in a greenhouse study exhibited boron toxicity symptoms (brown spotting near leaf tips). However, in field plots barley did not exhibit toxicity symptoms and headed out normally. Preliminary evidence indicated that boron was washed from the ash into the spoil in field conditions, diluting the element to non-toxic levels (Shaneman and Logan 1978). Lutwick et al. (1981) also found bottom ash to increase the amount of plant available boron in soil and noted boron toxicities on barley plants grown in the greenhouse. The statement was made that if internal drainage could be improved with ash addition then the problem of boron availability would be temporary.

Although initial work in the utilization of bottom ash has provided positive trends as a surficial amendment to sodic spoil, its use is not without some problems. Due to the coarse texture of the bottom ash and its high water-holding capacity, seeding and fertilizing operations are difficult. In order to minimize these difficulties, seeding and fertilizing is conducted in either early spring or late autumn, when the surface is frozen but snow cover is lacking (Natsukoshi 1981).

Erosion is another concern when using bottom ash as a surficial spoil amendment. Bottom ash has a tendency to erode if the spoil surface is contoured to slopes in excess of 15 degrees (Natsukoshi 1981). This in turn results in severe erosion of the underlying spoil.

3. STUDY AREA

3.1 LOCATION

The Vesta Mine area is situated on the south side of the Battle River, approximately 180 km southeast of Edmonton in East Central Alberta (Fig. 1). The plots occupy an area of 4.2 acres (1.7 ha) in LSD 2-SE 20-40-15-W4M. The mine is operated by Manalta Coal Ltd.

3.2 CLIMATE

The climate is continental and is characterized by relatively warm summers and cold winters. July is usually the warmest month of the year (17°C) while January is usually the coldest (-15°C). Total precipitation averages around 40.8 cm/yr (Bowser and Erdman 1947).

3.3 VEGETATION

Grasslands predominate the area surrounding the Vesta Mine. Tree growth is confined to isolated clumps, usually found on north facing slopes and in moist spots (Bowser and Erdman 1947).

The dominant trees and shrubs found in this area are: aspen poplar (*Populus tremuloides*), willow (*Salix* spp.), rose (*Rosa* ssp.), snowberry (*Symphoricarpos pauciflorum*), silver bush (*Elaeagnus argentea*), and balsam poplar (*Populus balsamifera*).

The principle species of native grasses present are: june grass (*Koeleria cristata*), slender wheat grass (*Agropyron trachycalum*), bearded wheat grass (*Agropyron subsecundum*), thickspike wheat grass (*Agropyron dasystachyum*), bluestem (*Agropyron smithii*), spike oat (*Avena Hookeri*), rough fescue (*Festuca scabrella*), sedges (*Carex* spp.), and bluejoint (*Calamagrostis canadensis*).

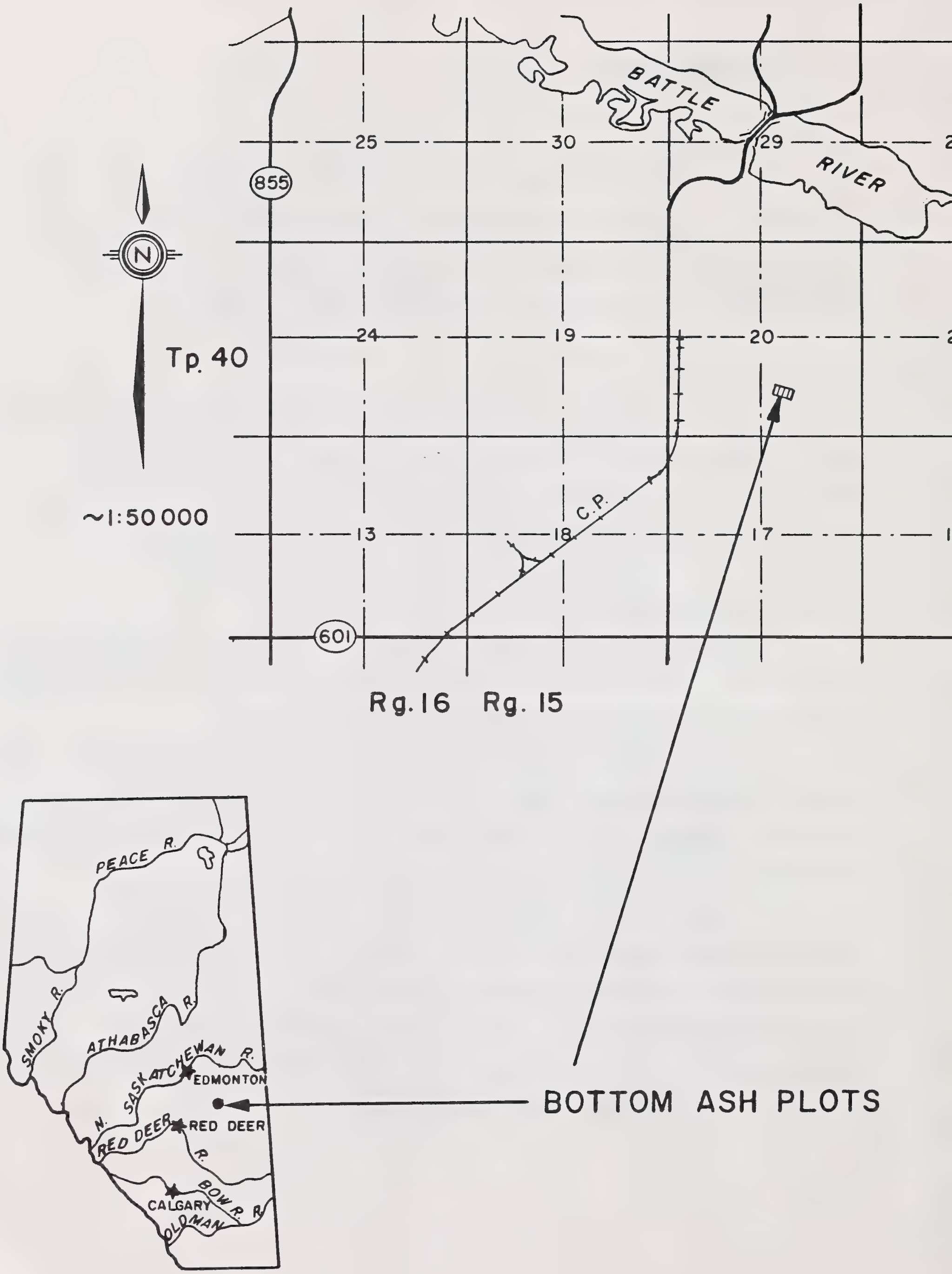


Figure 1. Location of the bottom ash plots.

3.4 GEOLOGY

Most of the surficial deposits in the study area consist of a level to gently undulating till plain. The glacial till forms a thin mantle approximately 3 m deep and consists mostly of material of local origin. Thus the composition of the till reflects the composition of the underlying bedrock (Brocke 1976).

The till in the Vesta Mine area contains diffuse calcium and magnesium carbonates. The principle salt present is sodium sulfate. Concentrations of water soluble salts vary from 0 to 50 me/100g. The presence of the salts coincides closely with areas of solonetzic soils.

In terms of texture, the surface tills have the following average composition: 41% sand, 31% silt, and 28% clay (Bayrock and Hughes 1962). The clay sized fraction of the till contains a large percentage of montmorillonite derived from the local late Cretaceous bedrock which is sodium saturated. This gives the till a granule-like consistence. Other clay minerals also present are illite, kaolinite, chlorite and fine-grained quartz.

The bedrock formation underlying the deposits described above is the Horseshoe Canyon Formation. This formation is entirely of late Cretaceous age and consists of soft-weathered, fine-grained clastic sediments deposited in a fresh to brackish water environment. The predominant lithologies are pale-weathered, fine-grained, bentonitic sandstones and siltstones interbedded with and grading vertically and laterally into grey to brown, bentonitic silty claystones. Coal and bentonite beds of variable thickness are present throughout the formation (Locker 1973). Bentonite is the prevailing constituent through the entire series of beds.

Average values for the major exchangeable cations in me/100gm are 11 for Na, 34 for Ca, and 9 for Mg. These values show that Ca, Na, and Mg, in that order of abundance, are commonly present as ions in the pore water of the formation. Potassium (K) is found in only negligible amounts. The distributions of the exchangeable cations vary with the formation, rock type and locality. Na is higher in portions of the formation where there is more montmorillonite present.

The average percentages of sand, silt and clay are 14, 51 and 35 respectively. The clay mineralogy consists of approximately 65% montmorillinite, 25% illite and 10% kaolinite and chlorite (Locker 1973).

3.5 SOILS

The soils of the area are classified as Black Solodized Solonetz developed on glacial till, and Dark Brown Solonetz developed on weathered bedrock where the till has been eroded. They generally have thin surface horizons and are affected by the salinity of the parent materials (Brocke 1976).

Soils in the area are rated as Class 3D for agriculture. That is, these soils have moderately severe production limitations from undesirable soil structure or slow permeability which restricts the range of crops and requires moderate conservation practices (Alberta Environment 1977). With good management these soils can be fairly productive for most crops common to the area.

4. MATERIALS AND METHODS

4.1 EXPERIMENTAL DESIGN

The plots were set up in a randomized complete block design (Fig. 2). Each plot measured 10 m by 20 m and was separated from neighboring plots by a 2 m buffer zone. There were three replicates consisting of 12 plots each. Each replicate was separated by a 10 m buffer zone.

The three rates of bottom ash tested were 10, 20, and 30 cm. Ash was incorporated into the spoil surface using a disc, chisel plow, and Kellough subsoiler. As a fourth method, ash was left as a blanket on top of the spoil.

4.2 PLOT CONSTRUCTION

Once surveyed in, the plots were cross ripped using a D8 crawler tractor with a three-point ripper to a mean depth of 1 m. The plots were then disced and harrowed. Bottom ash was hauled from the Battle River Generating Station to the plots using ash trucks. Since trucks were being used to haul the ash, the amounts applied to each plot were based on a truck load. Each truck load provided enough ash to cover one 10 m X 20 m plot to a depth of 10 cm. Therefore, each plot requiring ash received either 1 (10 cm), 2 (20 cm) or 3 (30 cm) loads of ash. Once the ash had been dumped, it was levelled over each plot using a D8 crawler tractor with a dozer. Depending on the plot design each plot was then disced, chisel plowed or subsoiled, and then harrowed. All plot construction activities were completed by December 1981.

4.3 SEEDING, FERTILIZING AND WEED CONTROL

Each plot was hand-sown using a cyclone seeder in May 1982. A seed mixture comprised of 25% each of Fairway Crested Wheatgrass, Tall Wheatgrass, Sodar Streambank Wheatgrass and Rambler Alfalfa (coated and pre-innoculated) was applied at a rate of 0.5 kg/plot. A fertilizer blend of 19% 11-51-0, 58% 34-0-0, and 23% 0-0-60 was also hand broadcast onto each plot at a rate of 6 kg/plot. Fertilizer rates were based on

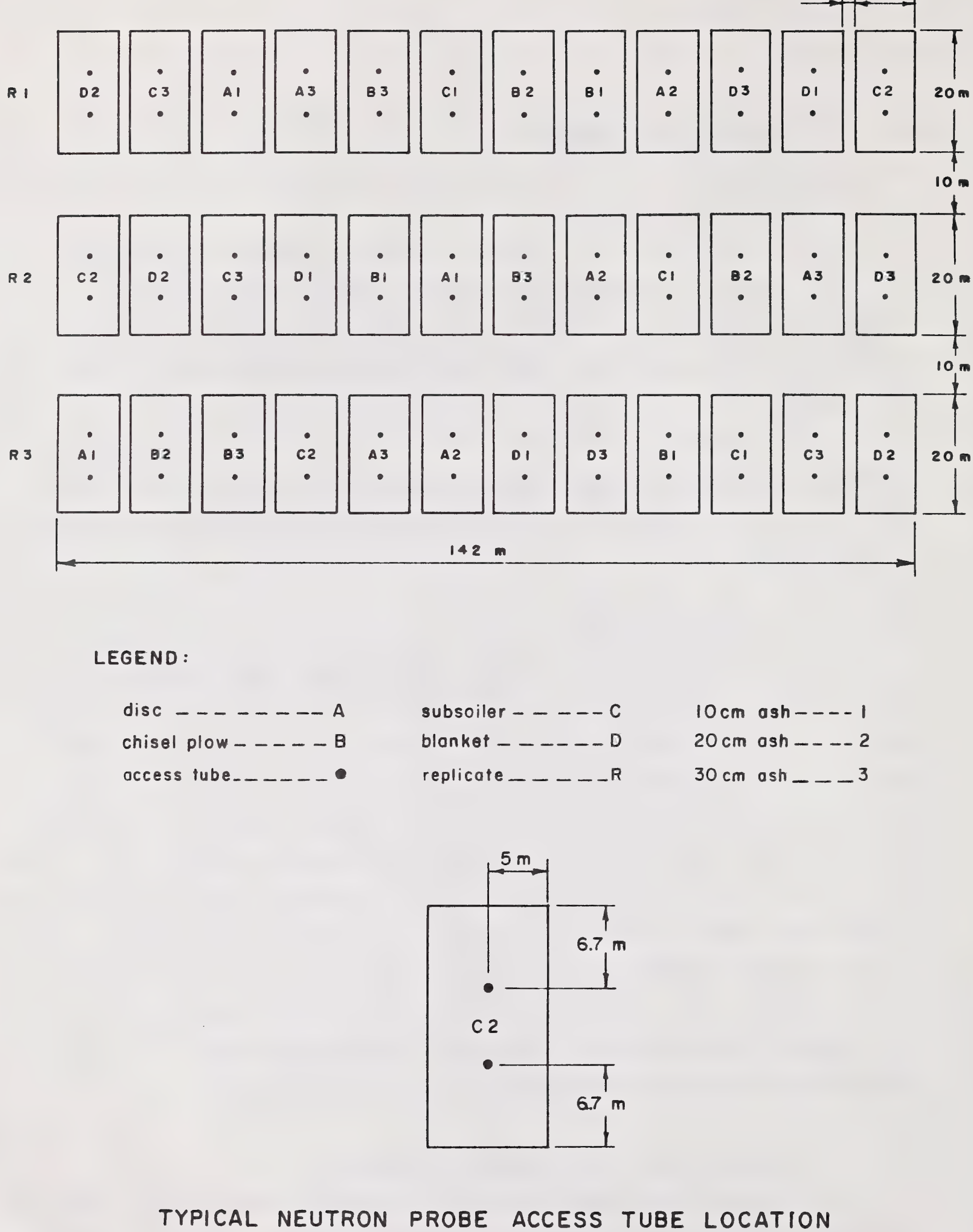


Figure 2. Experimental design of the bottom ash plots and location of the neutron probe access tubes.

soil tests. After the seed and fertilizer were applied each plot was lightly harrowed.

Cultural weed control began in August of 1983. Hand-picking of weeds was chosen over chemical control because chemicals were not recommended for use with seedling alfalfa. In 1984 and 1985, weeds were controlled by spraying the 2 m buffer zones with 2,4-D Ester 128. The large buffer zones between the replicates were disced to control the weeds.

4.4 SOIL SAMPLING AND ANALYSES

The plot areas were sampled in 15 cm increments from 0 to 60 cm after each plot had been staked, cross-ripped, and harrowed. This was done in order to characterize the spoil material before treatment (Appendix 10.1). After each plot had been sampled and the correct rate of bottom ash added, the surface application of ash was sampled from each plot for characterization purposes (Appendix 10.1).

Soil samples were taken in the fall of 1983, 1984 and 1985 (Appendix 10.2). Samples were taken in 15 cm increments from the surface to 90 cm. Two subsamples per increment were mixed and bagged, then sent to Norwest Labs in Edmonton, Alberta for selected analyses.

Procedures used for the following soil analyses are those outlined by McKeague (1978) as follows: pH (in water); EC (saturation extract); soluble salts (saturated paste extract); exchangeable cations and CEC (NH_4OAc at pH 7); 1/3 bar and 15 bar (pressure plates); particle size analysis (hydrometer); NH_4 and NO_3 (2N KCL); PO_4 (0.03N NH_4F and 0.03N H_2SO_4); K (NH_4OAc at pH 7); B (hot water extractable); Cu, Fe, Mn, Zn, Pb, and Ni (EDTA extractable); total C (dry combustion); $CaCO_3$ (gravimetric); and $CaSO_4$ (soluble Ca - soluble Ca at sat.%).

4.5 PLANT SAMPLING AND ANALYSES

A small plot-size Jari mower was used to cut down the vegetation on the plots each fall (1983 to 1985) leaving a 15 cm stubble (Appendix 10.3). The harvested material from each plot was then raked and weighed on site to obtain a wet weight. One composite sample was

taken at random from each plot. The samples were weighed, bagged, and sent to Norwest Labs to obtain moisture contents and have specific plant tissue analyses done. Plant analyses included N, P, K, Ca, Mg, and B, and were done using a HNO_3 - $HClO_4$ extraction. An atomic adsorption spectrophotometer was used for the elemental analyses.

4.6 SOIL MOISTURE MONITORING

A Campbell Pacific 501 neutron probe was used to monitor soil moisture on a monthly basis (Appendix 10.4). Two access tubes per plot were installed to a depth of 1.5 m in order to monitor moisture in 15 cm increments from 0 to 120 cm (Fig. 2). The access tubes had the following specifications: 1.67 m long, an outside diameter of 5 cm, and an inside diameter of 4.8 cm. An aluminum plate measuring 0.476 cm thick was welded to one end of each tube to prevent movement of water into the tube.

4.7 SOIL STRENGTH MEASUREMENTS

A Mark 1 Model Bush Recording Soil Penetrometer was used to measure soil strength in situ in 1985 only (Appendix 10.5). Fifteen measurements were taken in 3.5 cm intervals from 0 to 52.5 cm. Ten replicates were taken from each plot.

4.8 STATISTICAL ANALYSES

Statistical analyses were performed for the soil, plant and moisture variables (Appendix 10.6). The soil and plant variables were statistically analyzed over years and depths using a split-plot model by incorporating years and depths as split-plot factors (Steel and Torrie 1980). Statistical analyses were also done for each year with depth incorporated as a split-plot factor, and for each year at each depth. Trend analyses were performed for quantitative factors, and Tukey's test was used to evaluate significant differences between means.

In order to make the statistical analyses of the moisture data more manageable, the monthly moisture observations were averaged to produce one moisture value for each plot for each of four seasons: spring (March, April, May), summer (June, July, August), fall (September,

October, November), and winter (December, January, February). The moisture data was then analyzed in the same way as the soil and plant variables. Only the summer data will be discussed in this report as the trends were similar for each season.

5. RESULTS

Only those parameters significantly affected ($p<0.05$) by either method, rate, year, depth, or any subsequent interactions will be discussed in this section. When interpreting the results, unless a specific year is mentioned, there is no significant difference between years. Therefore, comparisons made (e.g., method x rate, method x depth) consist of datum from the three years monitored. When changes in parameters are discussed between increments, the depth used represents the lowest depth of a 15 cm increment. For example, 15 cm represents the 0 to 15 cm increment and 60 cm represents the 45 to 60 cm depth.

5.1 SOIL CHEMISTRY

5.1.1 Sat.%

Method of ash application affected the sat.% at depth in 1984 only (Fig. 3). The sat.% was lowest within the surface 15 cm for all methods, but increases occurred at different depths. Values significantly increased at: (1) 30 cm using the disc; (2) 15 cm using the chisel plow; (3) 30 cm using the subsoiler; and (4) 15 cm applying the blanket.

Rate of ash application affected the sat.% at each depth monitored (Fig. 4). The 20 and 30 cm rates reduced the sat.% within the 0 to 15 cm depth compared to the 10 cm rate, but only the 30 cm rate decreased it within the remaining depths. Values for sat.% were not significantly different for the 10 and 20 cm rates below 15 cm.

In general, the sat.% increased from the soil surface down to 90 cm for each rate and method of ash application.

5.1.2 pH

Values for pH decreased with increased rates of ash. Mean values were 8 for the 10 cm rate, 7.9 for the 20 cm rate and 7.8 for the 30 cm rate. Regardless of the rate or method of ash application , pH changed with depth in the plots. The pH increased from the soil surface

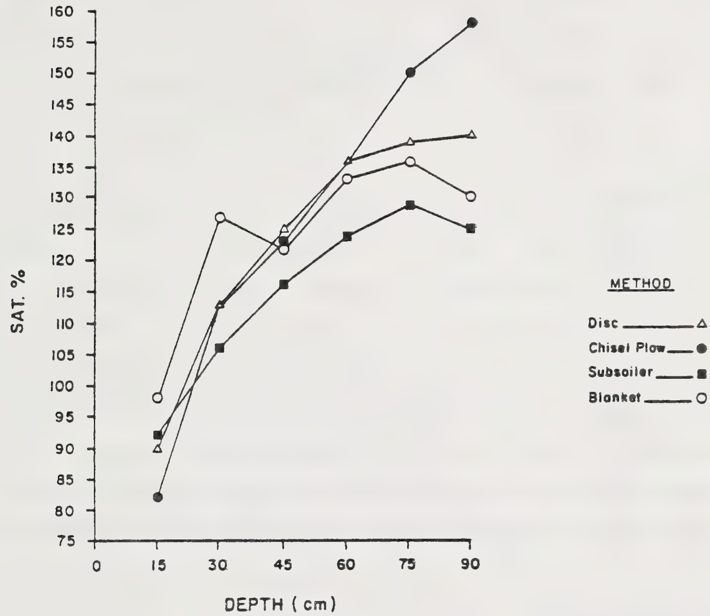


Figure 3. Effect of method on the SAT. % at each depth in 1984.

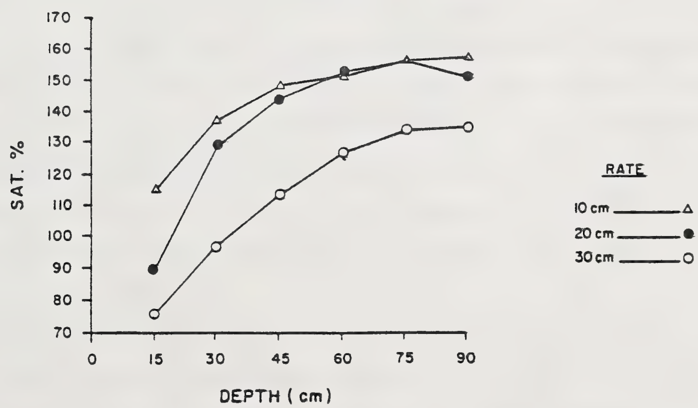


Figure 4. Effect of rate on the SAT. % at each depth.

(7.8) down to 45 cm (8.0), remained the same at 60 cm, and then decreased down to 90 cm (7.9) to values which were not significantly different than those within the surface 30 cm. These changes in pH were statistically different but not chemically or biologically significant.

5.1.3 EC

There were differences in values for EC between rates of ash at the 0 to 15, 60 to 75, and 75 to 90 cm depths (Fig. 5). Within the surface 15 cm, the EC decreased as the rate of ash increased. Values in mS/cm were 4.7 (10 cm), 3.8 (20 cm), and 2.3 (30 cm). The reverse occurred at the other two depths. Values for EC increased as the rate of ash increased. Mean values in mS/cm were 4.3, 5.0, and 5.8 at the 60 to 75 cm depth, and 3.8, 5.2 and 5.4 at the 75 to 90 cm depth.

Values for EC decreased with increasing depth for the 10 cm rate, and increased with increasing depth for the 20 and 30 cm rates.

5.1.4 Ca, Mg, and Na

Both soluble Ca and Mg concentrations increased with increasing rates of ash at the 60 to 75 and 75 to 90 cm depths (Fig. 6). Concentrations of Ca in me/L with increasing rates of ash were 2.6, 4.7 and 6.3 at the 60 to 75 cm depth, and 1.9, 5.4 and 6.0 at the 75 to 90 cm depth. Corresponding concentrations of Mg in me/L were 1.1, 1.7 and 2.2 at the 60 to 75 cm depth and 0.7, 2.2 and 2.2 at the 75 to 90 cm depth.

Concentrations of soluble Na decreased within the 0 to 15 cm depth, and increased within the 75 to 90 cm depth with increasing rates of ash (Fig. 6). Concentrations in me/L with increasing rates were 54.3, 42.0 and 25.0 within the surface 15 cm and 43.0, 56.7 and 61.1 at the 75 to 90 cm depth.

For each of the soluble cations, concentrations decreased from the soil surface down to 90 cm for the 10 cm rate, and increased down to 90 cm for the remaining rates.

5.1.5 SAR

In 1983 and 1985, the SAR decreased with increased rates of ash at the 0 to 15 and 15 to 30 cm depths (Fig. 7). Values in 1983 with

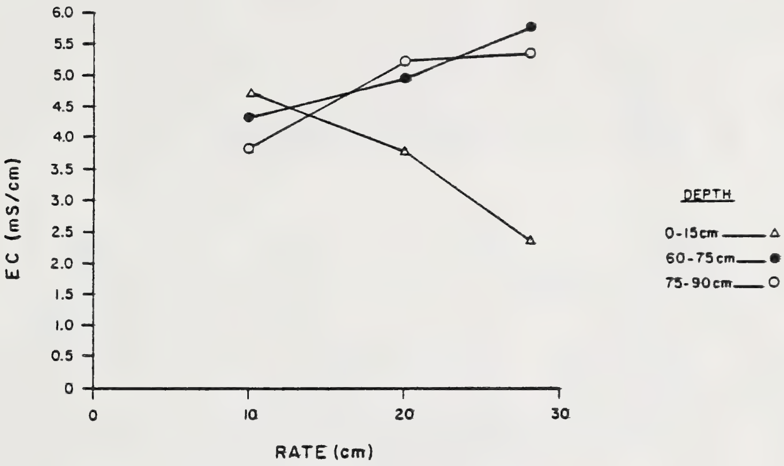


Figure 5. Effect of rate on the EC at various depths.

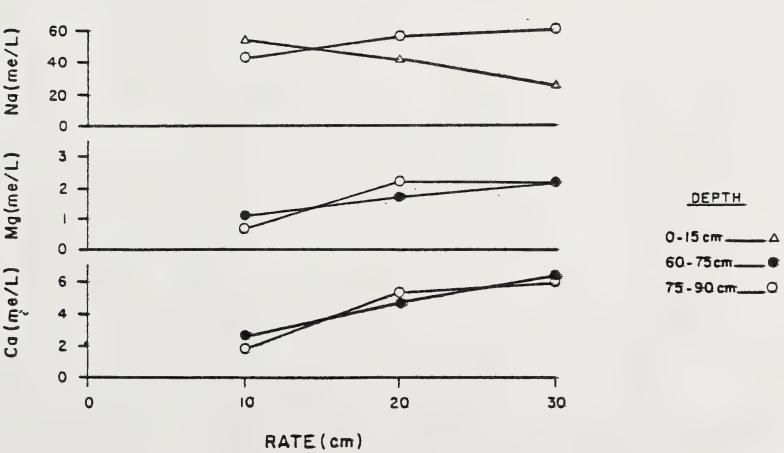


Figure 6. Effect of rate on soluble Ca, Mg and Na at various depths.

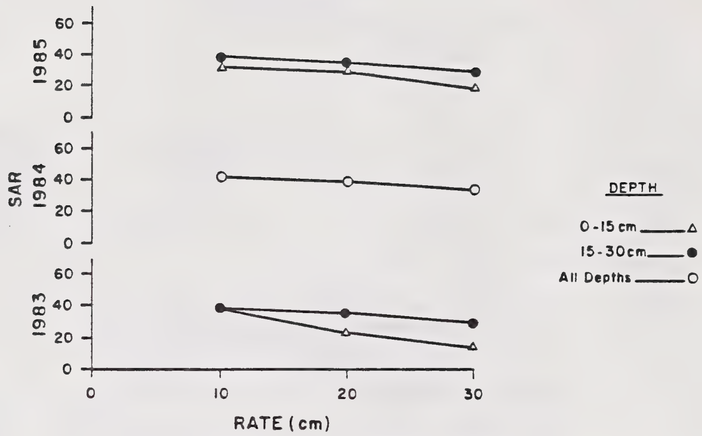


Figure 7. Effect of rate on the SAR at various depths.

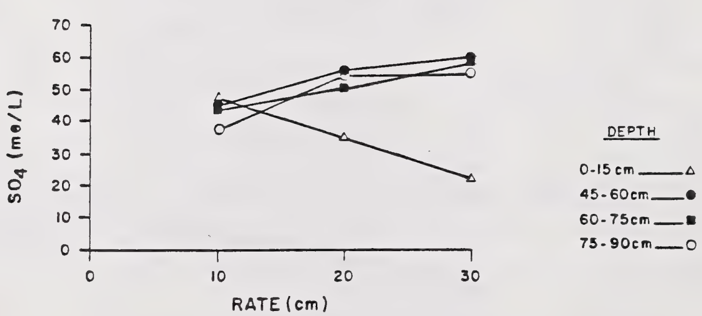


Figure 8. Effect of rate on SO_4 concentrations at various depths.

increasing rates were 40, 23 and 14 at the 0 to 15 cm depth and 40, 34 and 29 at the 15 to 30 cm depth. In 1985 values were 32, 30, 19, and 39, 34, and 29 respectively. In 1984 concentrations at all depths decreased in a linear fashion with increasing rates. Mean values were 41.5, 39.1 and 33.6. For each rate of ash, the SAR increased from the soil surface down to 90 cm.

5.1.6 SO_4

Sulfate concentrations were affected by the different rates of ash at the 0 to 15, 45 to 60, 60 to 75 and 75 to 90 cm depths. With increasing rates of ash, SO_4 decreased in a linear fashion within the surface 15 cm (Fig. 8). Concentrations were 48.1, 35.4 and 21.9 me/L respectively. Below 45 cm, SO_4 concentrations increased in a linear fashion with increasing rates of ash. Concentrations in me/L were 46.1, 57.8 and 61.2 at 45 to 60 cm; 44.0, 51.1 and 59.8 at 60 to 75 cm; and 38.5, 55.1 and 56.1 at 75 to 90 cm.

Concentrations of SO_4 decreased from the soil surface down to 90 cm for the 10 cm rate, and increased from the soil surface down to 90 cm for the 20 and 30 cm rates.

5.1.7 B

Of the three years monitored, concentrations of plant available B were highest in 1983 within the surface 30 cm (Fig. 9). Values in ppm were 12.23 in 1983 and a mean value of 5.64 in 1984 and 1985 for the 0 to 15 cm depth. Within the 15 to 30 cm depth concentrations were 6.39 in 1983 and a mean value of 3.48 in 1984 and 1985.

B concentrations were highest in 1983 (8.12 ppm) than either 1984 or 1985 (3.72 ppm) for the 30 cm rate, and higher in 1983 (3.18 ppm) than 1985 (1.63 ppm) for the 20 cm rate.

Within the 0 to 15, 15 to 30 and 30 to 45 cm depths, concentrations of B increased with increased rates of ash (Fig. 10). Concentrations in ppm for the 10, 20 and 30 cm rates at each depth were: 3.94, 6.84, and 12.73 (0 to 15 cm); 1.72, 2.66, and 8.97 (15 to 30 cm); and 1.24, 1.77, and 3.86 (30 to 45 cm). In general, B concentrations decreased with increasing depth for each rate of ash.

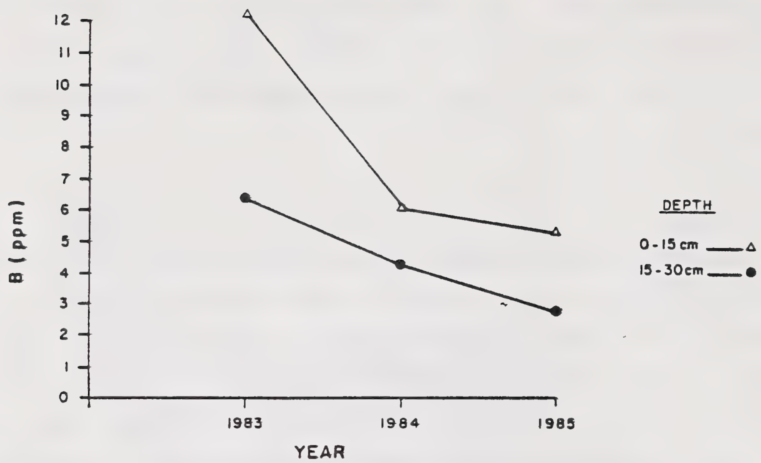


Figure 9. Effect of year on B concentrations at various depths.

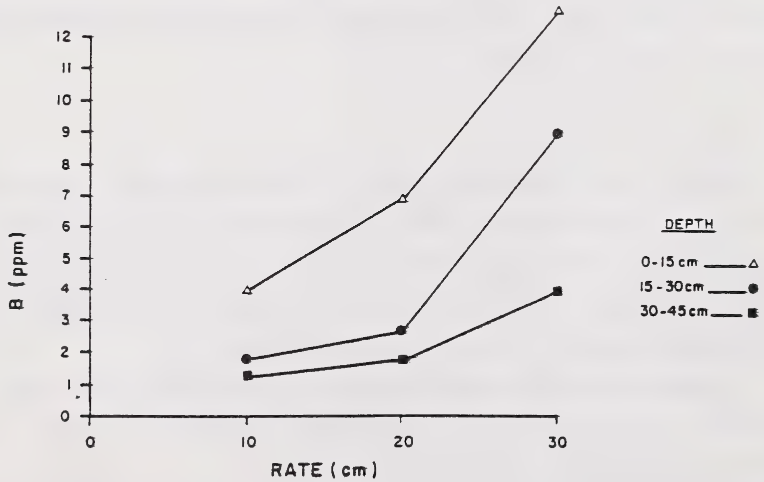


Figure 10. Effect of rate on B concentrations at various depths.

Within the surface 15 cm, concentrations of B were lowest for the chisel plow method (5.56 ppm) and highest for the blanket method (10.44 ppm). The disc had lower B concentrations (6.99 ppm) than the blanket method, and the subsoiler had higher concentrations (8.36) than the chisel plow. Concentrations of B were highest within the surface 15 cm for each method, but the depth at which concentrations became significantly lower differed for each method. The depths were 15 cm for the disc and blanket, and 30 cm for the subsoiler and chisel plow. In general, concentrations of B decreased with increasing depth for each method.

5.1.8 % OM

In 1985 %OM was highest (10.5%) as compared to 1983 or 1984 (6.5%) which were not significantly different. The amount of OM also increased with increased rates of ash. Values in percent were 5.6, 6.3 and 11.8 for the 10, 20 and 30 cm rates.

5.2 SOIL STRENGTH

Method of ash application had no effect on soil strength within the surface 21 cm or depths below 45.5 cm (Table 2). Between 21 and 45.5 cm the subsoiler resulted in lower soil strengths than the disc, and between 24.5 cm and 42 cm it produced values lower than the chisel plow. From 35 to 45.5 cm the blanket method produced lower soil strengths than the disc and chisel plow methods. Therefore, in order of decreasing soil strengths between 21 and 45.5 cm the methods were rated as disc and chisel plow (0.34 bar), blanket (0.29 bar) and subsoiler (0.20 bar).

Rate of bottom ash had no effects on the surface 3.5 cm or depths below 49 cm. Between 3.5 and 49 cm, soil strength decreased with increased rate of ash (Fig. 11). In general, the soil strength decreased from 0.31 bar at the 10 cm rate, to 0.27 bar at the 20 cm rate, and to 0.21 bar at the 30 cm rate.

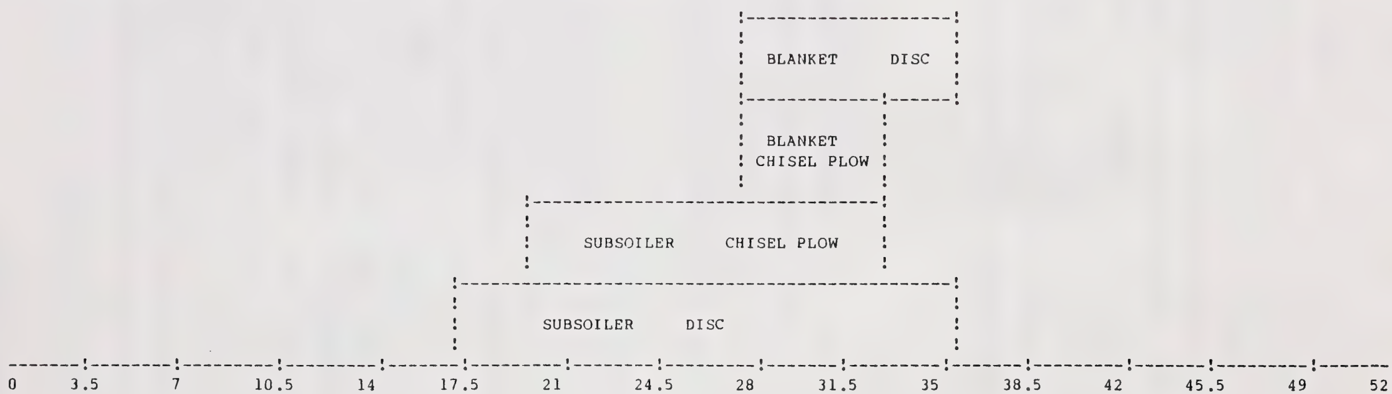
5.3 SOIL MOISTURE

The only difference between methods occurred at the 30 to 45 cm depth. The blanket had the highest moisture content (MC) (33.73%) and

Table 2. Effects of method on soil strength at each depth monitored.

METHOD	Soil Strength (bar)														
	3.5 cm	7 cm	10.5 cm	14 cm	17.5 cm	21 cm	24.5 cm	28 cm	31.5 cm	35 cm	38.5 cm	42 cm	45.5 cm	49 cm	52.5 cm
disc	0.00 a	0.08 a	0.16 a	0.20 a	0.24 a	0.27 a	0.30 a	0.31 a	0.34 a	0.36 a	0.37 a	0.39 a	0.40 a	0.40 a	0.41 a
chisel plow	0.00 a	0.08 a	0.15 a	0.18 a	0.22 a	0.25 ab	0.29 a	0.32 a	0.34 a	0.36 a	0.37 a	0.38 a	0.38 ab	0.38 a	0.39 a
subsoiler	0.01 a	0.10 a	0.14 a	0.17 a	0.19 a	0.21 b	0.23 b	0.25 b	0.26 b	0.26 b	0.28 b	0.31 b	0.33 b	0.35 a	0.36 a
blanket	0.00 a	0.08 a	0.16 a	0.18 a	0.21 a	0.25 ab	0.27 ab	0.28 ab	0.29 ab	0.30 b	0.30 b	0.31 b	0.34 b	0.35 a	0.37 a

Means with the same subscript (a,b,c) within a column are not significantly different at p<0.05.



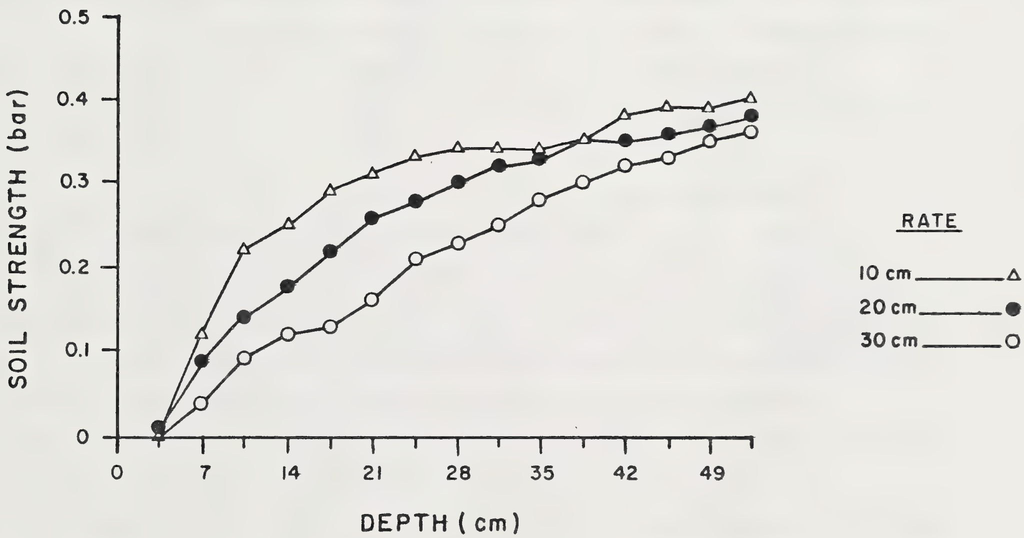


Figure 11. Effect of rate on soil strength at depth.

the disc the lowest (30.24%). The chisel plow and subsoiler were similar to both the blanket and disc and had a mean MC of 33.36%. In general, each method had increasing values for MC with depth (Fig. 12).

Within the surface 45 cm, MC decreased with increasing rates of ash (Fig. 13). Values in percent for increasing rates of ash were: 17.94, 14.96 and 10.26 (0 to 15 cm); 30.24, 27.46 and 22.43 (15 to 30 cm); and 34.11, 31.60 and 30.79 (30 to 45 cm). Below 45 cm MC values were not significantly different until the 105 to 120 cm depth. Within this depth, the trend was reversed. Moisture percentages increased with increasing rates (35.80, 37.25 and 38.04% respectively).

Moisture was highest at all depths in 1983 as compared to 1984 and 1985 which were similar (Fig. 14).

5.4 PLANT VARIABLES

There was a significant increase in yield with increasing rates of ash. In t/ha, yields were 1.07 (10 cm), 1.41 (20 cm) and 1.82 (30 cm). Yields were lower in 1984 (1.07) than either of 1983 or 1985 (1.62) which were not significantly different from each other.

Concentrations of B increased with increasing rates of ash. Concentrations in ppm were 43.4 (10 cm), 50.0 (20 cm), and 52.3 (30 cm).

Percentages of N, P, and K were lowest in 1983 and were not significantly different in 1984 and 1985 (Fig. 15). The reverse was true for Ca and Mg. Concentrations were highest in 1983 and not significantly different in 1984 and 1985.

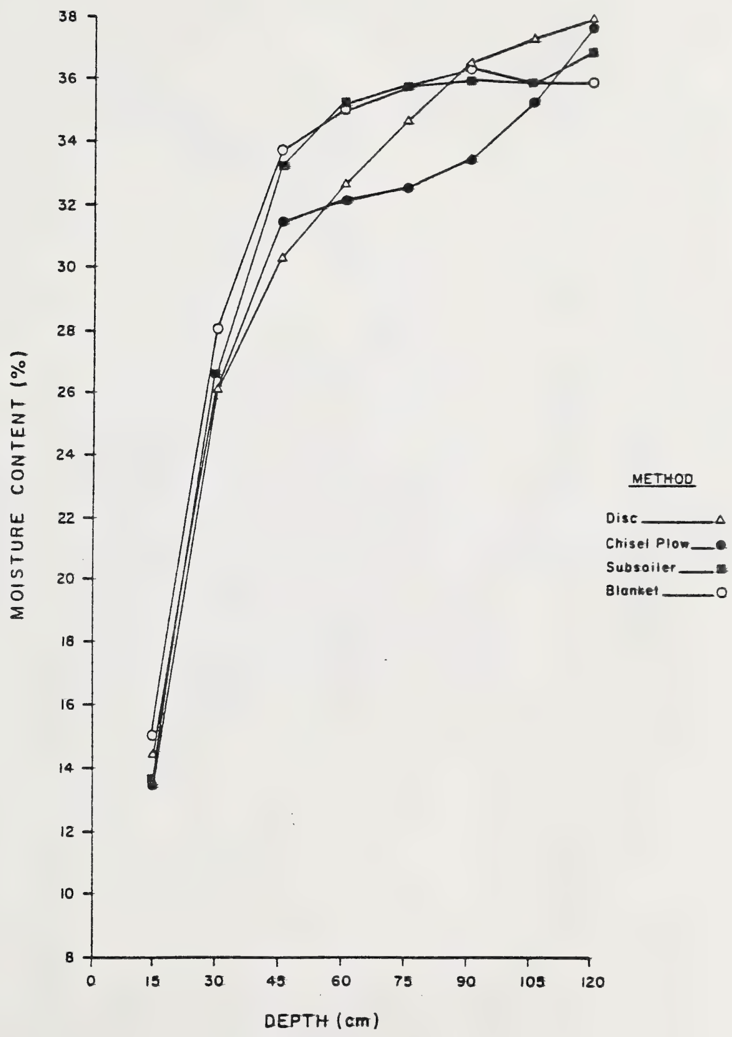


Figure 12. Moisture content at different depths for each method.

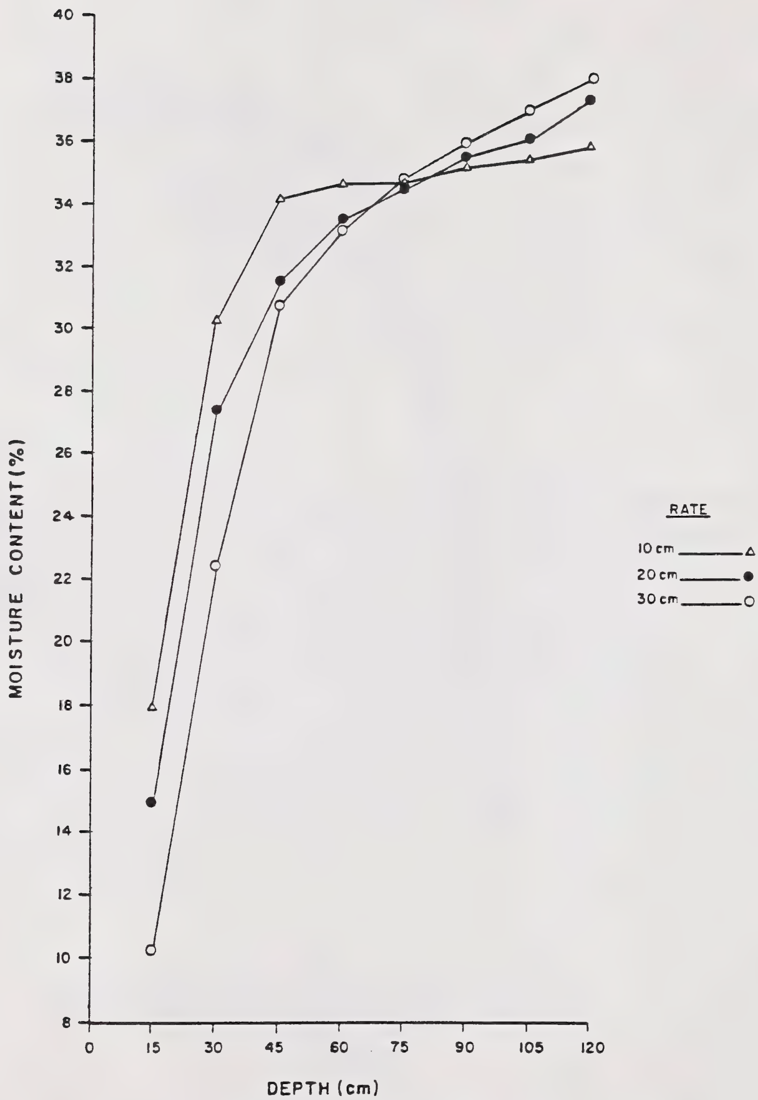


Figure 13. Moisture content at different depths for each rate.

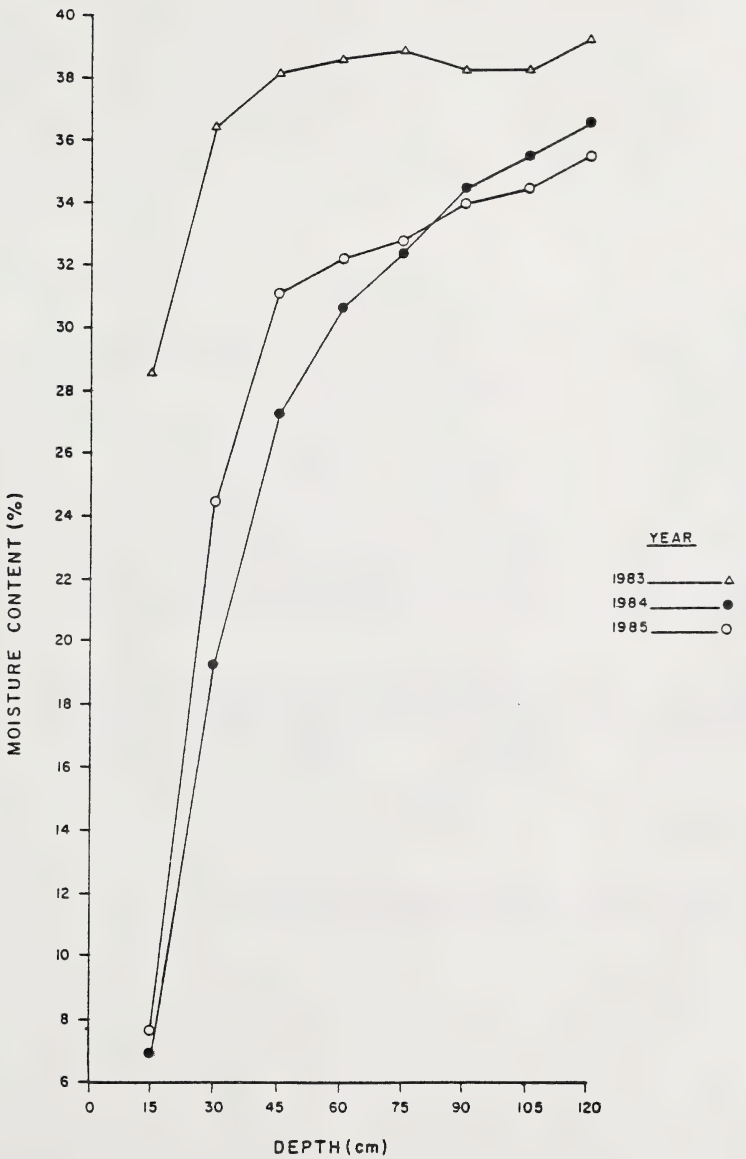


Figure 14. Moisture content at different depths for each year.

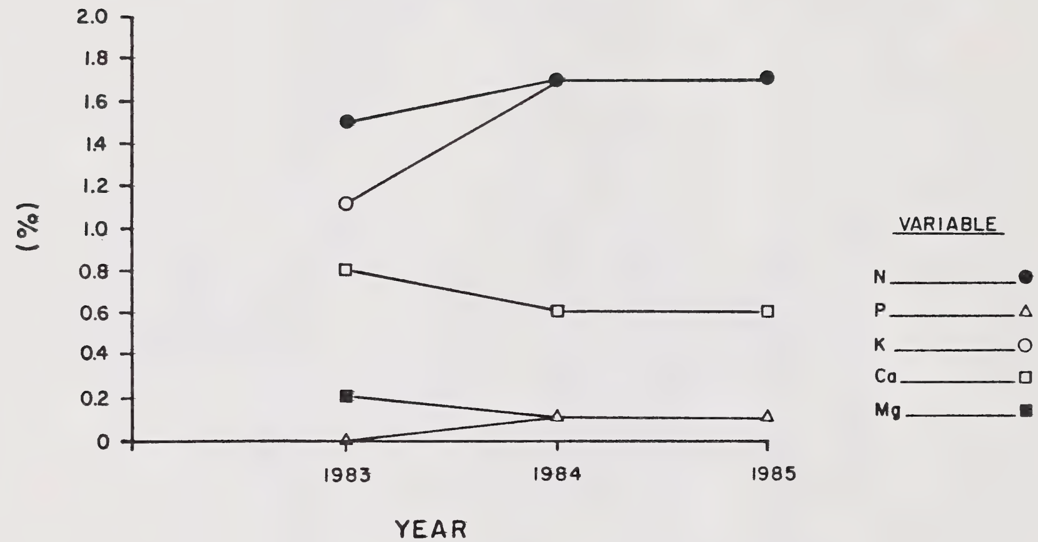


Figure 15. Effect of year on plant variables.

6. DISCUSSION

Before initiating the discussion it is worthwhile to repeat the objectives of the study. They were to determine the best rate and method of application of bottom ash to sodic spoil in terms of reducing the effects of excess sodium and promoting vegetative growth. These objectives should be kept in mind while reading the discussion and conclusions sections of this report.

6.1 METHOD OF BOTTOM ASH APPLICATION

The method of bottom ash application had few significant effects on the soil variables. The subsoiler method decreased the sat.% and increased B concentrations within the surface 30 cm of the plots. It was also the most effective method in terms of having the lowest soil strength measurements between 21 and 45.5 cm. The values for sat.% and B indicate that effective mixing of ash and spoil occurred down to a maximum depth of 30 cm. The low soil strength values indicate that the teeth of the subsoiler were able to penetrate down to 45.5 cm and loosen the spoil material.

Within the surface 15 cm the blanket method reduced the sat.% and had the highest B concentrations. Below 15 cm, this method had the second lowest soil strength measurements and had the greatest amount of moisture within the 30 to 45 cm depth. Field observations showed that moisture seemed to concentrate at the ash-spoil interface with the blanket treatments. This is confirmed by the high moisture at the 30 to 45 cm depth and reduced soil strength values. A problem with the 30 cm blanket treatments in the field was trafficability. At the higher ash rates, it was very difficult to use farm machinery to seed, fertilize and cultivate the plots.

In a similar fashion to the subsoiler, the disc method reduced the sat.% within the surface 30 cm. Unlike the subsoiler, the disc had increased B concentrations within the surface 15 cm. The disc had the highest soil strength values and had the lowest MC values at the 30 to 45 cm depth. The disc method had no effect on any of the soil parameters

monitored below 30 cm. This reflects the fact that the disc is a surface tillage treatment.

The chisel plow method decreased the sat.% within the surface 15 cm and also had the lowest B concentrations within that depth. The chisel plow had increased B concentrations within the top 30 cm, and like the disc, had the highest soil strength values. The chisel plow had its greatest effect within the surface 30 cm of the plots.

As was mentioned previously, each of the methods had increased B concentrations within the surface 15 cm. Even though each method resulted in different B concentrations, all but the chisel plow had values in the toxic range (5.7 ppm) for plant growth (Table 3). The chisel plow had values in the high range (1.5+ ppm). Concentrations of B within the surface 15 cm reflect the amount of mixing which occurred. The blanket treatment had the highest concentration and was not mixed while the chisel plow had the lowest and resulted in maximum mixing.

The method of ash application had no effect on plant yield or nutrients, therefore was not a limiting factor to plant growth.

6.2 RATE OF BOTTOM ASH APPLICATION

The rate of bottom ash application produced the most significant effects on both the plant and soil variables. As the rate of ash increased, the chemistry of the surface 15 cm of the plots was improved. The EC along with parameters reflecting sodicity (pH, sat.%, SAR, Na_2SO_4) were decreased. Along with an improvement in chemistry was a corresponding increase in yield and OM content in the soil. Therefore, as bottom ash was increased from 10 to 30 cm, the chemistry of the surface was improved which promoted increased crop growth. In terms of yield, on a wet weight basis from 1983 to 1985 the yields averaged 1.07, 1.41, and 1.82 t/ha respectively for the 10, 20, and 30 cm rates. Yields in Census Division No. 7 (Agricultural Reporting Area 4A) within which the plots fell, reported a mean yield of 2.9 t/ha, for the same time period. Yields for each of the application rates were below those reported but increased with increasing rates of ash.

Table 3. B in the bottom ash plots as compared to Alberta soils.

Variable		Depth (cm)	B (ppm)[1]
Method:	chisel plow		5.6
	disc		7.0
	subsoiler		8.4
	blanket		10.4
Rate:	10 cm	0-15	3.9
		15-30	1.7
		30-45	1.2
	20 cm	0-15	6.8
		15-30	2.7
		30-45	1.8
	30 cm	0-15	12.7
		15-30	9.0
		30-45	3.9
Literature:	low[2]		0.0-0.8
	medium[2]		0.8-1.5
	high[2]		1.5+
	toxic[3]		5.7

1 Hot water extractable
2 Alberta Agriculture 1983
3 Gupta et al. 1985

While the surface of the spoil was improved, there was an increase in EC and corresponding soluble salts below 60 cm. Therefore, increased rates of ash promoted leaching from the soil surface down to below 60 cm. This is also seen by observing the trends in the concentrations of soluble Na, Ca, Mg and SO_4. At the 10 cm rate, concentrations decreased down to 90 cm. At the 20 and 30 cm rates, concentrations increased down to 90 cm. Values for SAR, pH and sat.% decreased at all depths with increasing rates of ash. The changes in soil moisture with changing ash rates also reflected a leaching environment. As the rates of ash increased, the moisture with the 0 to 45 cm depth decreased, and increased within the 105 to 120 cm depth. Moisture movement downwards would have been enhanced by the decreased soil strength with increased ash rates between 3 and 48.5 cm.

B concentrations increased within the surface 45 cm with increased ash rates. According to Table 3, B was present at medium to high levels using the 10 cm rate. It was at toxic levels within the surface 15 cm for the 20 cm rate, and within the surface 30 cm for the 30 cm rate. Even though B was at toxic concentrations within the soil, it was not reflected in the plant analyses (Table 4). All of the micronutrients in the alfalfa-grass hay mixture were in the sufficient range except for Fe, which was in the high range.

Table 4. Comparison of micronutrient concentrations in forage from the bottom ash plots and those in the Alberta literature.

Nutrient	Alberta	Range	Bottom Ash Plots	Range
% Ca	1.31[1]		0.66	
% Mg	0.25[2]		0.13	
% K	1.44[2]		1.26	
% N			1.65	
% P	0.20[1]		0.11	
B (ppm)	5.00[3]	low[3]	49.57	sufficient[3]
Cu(ppm)	7.05[2]	marginal[3]	11.42	sufficient[3]
Fe(ppm)	261.50[2]	high[3]	346.33	high[3]
Mn(ppm)	36.50[2]	sufficient[3]	38.97	sufficient[3]
Zn(ppm)	23.00[2]	sufficient[3]	48.63	sufficient[3]

[1] Alberta Agriculture 1981
[2] Alberta Agriculture 1984 and Alberta Agriculture 1985
[3] Alberta Agriculture 1983

7. CONCLUSIONS

1. Of the three rates tested (10, 20, 30 cm) the best rate of bottom ash to be applied to sodic spoil was 30 cm. The rate causing poorest results was 10 cm.
2. A rate of 30 cm of bottom ash improved the chemistry, decreased the soil strength, and increased the soil moisture of the spoil.
3. A rate of 30 cm of bottom ash promoted leaching as was seen by a decrease in moisture within the surface of the spoil accompanied by an increase in moisture at depth.
4. B concentrations increased in both spoil and plant tissues as the rate of ash increased. Concentrations were at toxic levels in the soil at the 20 and 30 cm application rates, but the toxicities were never reflected in any plant toxicity symptoms.
5. Of the four methods tested (disc, chisel plow, subsoiler, and blanket) the best method of bottom ash incorporation into sodic spoil was subsoiling. The method producing the poorest results was the disc.
6. The subsoiler effectively mixed ash and spoil within the surface 30 cm, and decreased the soil strength at depth.
7. All of the methods resulted in B concentrations in the toxic range for plants. These toxicities never occurred in the plant tissues.
8. The blanket method at the 30 cm ash rate created trafficability problems which made seeding, fertilizing and cultivation of the plots very difficult.
9. Method of bottom ash application had no effect on any of the plant variables.
10. Hay yields for each of the rates were below those reported for adjacent farm lands, but increased with increasing rates of ash.

11. Rate was more important than method in terms of significant effects on plant and soil variables.
12. Based on the results of this study, the most appropriate method and rate of ash application to sodic spoil is to topdress the spoil with 30 cm of bottom ash and mix it in using a subsoiler.

8. RECOMMENDATIONS

1. Further work should be done to compare the trafficability aspects of the three rates. During plot construction farm machinery and coring trucks had difficulty driving on the 30 cm plots. The ash seemed to stabilize and strengthen over time, but this was not measured. A study should be undertaken to see how the 3 rates compare in terms of use by vehicles and animals. Possibly the 20 cm rate would be the best for pasture or hay lands.
2. Costs should be compared to see which method is most cost effective, as subsoiling is expensive. Possibly the blanket treatment followed by the chisel plow would be next best method in terms of cost and results.
3. The possibility of using bottom ash as an amendment to solonetzic soils should be entertained. Local farmers in the area of the mine were quite interested in using bottom ash after seeing the plots.

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10. APPENDICES

10.1 SODIC SPOIL AND BOTTOM ASH CHARACTERIZATION

Results of the chemical and physical analyses performed on sodic spoil from the plots are listed in Tables 5 and 6. Similar analyses performed on bottom ash are listed in Table 7.

10.2 SOIL DATA: 1983 TO 1985

Results of the mean soil analyses performed on plot samples from 1983 to 1985 are listed in Tables 8 to 19.

10.3 PLANT DATA: 1983 TO 1985

Results of the mean analyses performed on plant tissue samples from the plots during the period of 1983 to 1985 are listed in Tables 20 to 22.

10.4 MOISTURE DATA: 1983 TO 1985

Results of the seasonal soil moisture readings taken using the neutron probe during the period of 1983 to 1985 are listed in Tables 23 to 34.

10.5 SOIL STRENGTH MEASUREMENTS: 1985

Results of the soil strength measurements taken on the plots in 1985 are listed in Table 35.

10.6 STATISTICAL ANALYSES

Results of the ANOVA performed on soil samples are listed in Table 36. Results for the plant samples are listed in Table 37. Soil strength results are listed in Table 38 and soil moisture analyses in Table 39.

Table 5. Chemical characterization of spoil.

Depth (cm)	pH	Sat. (%)	EC (mS/cm)	Water Soluble Salts: Ca	Mg	Na	K	SO_4	HCO_3	NO_3	Cl	SAR	Extractable Cations: Ca	Mg	Na	K	CEC	$CaCO_3$ Equiv (%)	$CaSO_4$ (me/100g)	Trace Elements[2]: Cu	Zn	Fe	B
				me/L									me/100 g							ppm			
0-15																							
mean	8.0	154	3.3	3.4	1.5	39.4	0.9	42.0	7.0	1.2	0.6	25	22.0	5.9	17.0	1.3	33.1	3.8	2.6	5.5	5.1	16.9	1.0
S.D.±	0.2	24	1.2	3.9	1.4	13.8	0.5	18.8	1.6	0.8	0.5	5	2.1	0.6	1.7	0.1	4.0	1.3	1.8	1.9	2.7	4.1	0.1
15-30																							
mean	7.9	156	3.1	3.9	1.6	38.6	0.8	39.3	6.9	1.2	0.7	23	21.5	5.9	17.5	1.2	33.1	4.9	2.1	7.0	5.2	19.1	0.9
S.D.±	0.3	28	1.3	5.6	1.6	19.6	0.5	23.5	1.9	0.9	0.6	6	1.9	0.9	6.2	0.1	1.9	3.7	1.4	3.1	2.2	5.6	0.2
30-45																							
mean	7.9	161	3.2	4.0	1.7	36.4	0.7	37.5	6.6	1.1	0.7	22	21.2	5.9	16.5	1.2	33.3	5.3	2.0	6.8	4.3	22.0	1.0
S.D.±	0.3	33	1.7	5.3	2.0	17.4	0.5	24.5	1.9	0.7	0.7	8	2.7	1.2	2.4	0.1	2.5	7.9	1.6	3.0	1.3	11.5	0.2
45-60																							
mean	7.9	154	3.3	3.8	1.8	38.2	0.8	40.4	6.8	1.1	0.9	23	21.2	5.9	16.7	1.2	34.3	3.6	2.2	6.5	4.2	20.5	1.0
S.D.±	0.4	32	1.5	5.6	2.6	17.2	0.3	26.0	2.0	0.7	1.2	7	2.7	1.2	2.1	0.1	2.6	1.7	1.5	2.0	1.1	6.4	0.2
overall																							
mean	7.9	156	3.2	3.8	1.7	38.1	0.8	39.8	6.8	1.2	0.7	28	21.5	5.9	16.9	1.2	33.4	4.4	2.2	6.4	4.7	19.6	1.0
S.D.±	0.3	30	1.4	5.1	2.0	17.0	0.4	23.2	1.8	0.8	0.8	6	2.4	1.0	3.5	0.1	2.9	4.5	1.6	2.5	1.9	7.2	0.1

[1] Means of 36 samples.

[2] Means of 6 samples.

Table 6. Physical characterization of spoil.[1]

Depth (cm)	Particle Size Distribution S	Si	C	Texture	Moisture Content FC	WP
	--------- %	-------------			----% H_2O	----
0-15						
mean	15	46	39	SiCL	94.9	40.2
S.D±	5	3	3		11.9	9.6
15-30						
mean	18	44	38	SiCL	95.3	40.7
S.D±	8	5	5		15.3	8.8
30-45						
mean	17	45	38	SiCL	97.6	41.1
S.D±	7	5	4		18.3	8.0
45-60						
mean	16	45	39	SiCL	96.5	40.3
S.D±	6	5	4		18.8	9.9
overall						
mean	17	45	38	SiCL	96.1	40.6
S.D±	6	4	4		16.2	9.0

[1] Means of 36 samples.

Table 7. Chemical and physical characterization of bottom ash.[1]

Analysis		Mean	Standard Deviation(±)
pH		7.9	0.3
Sat. %		87.0	19.0
EC (mS/cm)		2.0	1.0
Water Soluble Salts	Ca	2.7	1.6
(me/L)	Mg	1.1	0.6
	Na	17.5	11.7
	K	0.6	0.3
	SO_4	17.2	13.4
	HCO_3	4.8	1.8
	NO_3	0.2	0.3
	Cl	1.1	2.8
SAR		13.0	6.5
Extractable Cations	Ca	11.4	1.5
(me/100 g)	Mg	1.9	0.3
	Na	3.2	1.6
	K	0.4	0.0
CEC (me/100g)		14.6	0.5
$CaCO_3$ Equivalent (%)		0.9	0.7
Trace Elements	Cu	2.4	1.0
(ppm)	Zn	1.2	1.0
	Mn	3.6	2.6
	Fe	41.6	9.3
	B	2.9	1.2
	Pb	1.8	1.1
	Cd	0.3	0.2
	Ni	38.9	20.7
Particle Size Distribution			
	S	67.0	5.0
(%)	Si	23.0	2.0
	C	10.0	3.0
Texture		SL	
FC (%)		34.6	12.4
WP (%)		18.8	10.2

[1] Means of 36 samples except for extractable cations and particle size analysis which were based on 3 samples.

Table 8. Means of analyses performed on plot samples using the disc method in 1983.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	98.33	7.93	5.34	5.83	1.83	60.67	58.67	31.23	6.17	2.57
	15-30	125.67	7.87	5.93	5.07	1.83	67.53	64.17	36.50	1.83	-
	30-45	142.67	8.00	4.65	3.27	0.93	52.87	49.47	39.10	0.80	-
	45-60	151.00	8.03	4.41	2.40	0.97	46.23	41.07	37.97	0.90	-
	60-75	146.33	8.07	5.68	3.10	1.27	67.27	61.17	47.70	0.87	-
	75-90	153.67	8.10	3.89	1.77	0.67	43.97	42.73	41.33	0.83	-
20	0 -15	82.67	7.93	2.25	1.50	0.63	22.80	21.73	21.60	3.57	3.03
	15-30	132.33	8.07	3.56	2.30	0.87	39.70	38.90	32.60	2.07	-
	30-45	149.33	8.00	4.55	3.07	1.07	48.90	47.60	37.27	1.33	-
	45-60	141.33	7.90	5.86	8.63	2.60	63.30	65.40	32.27	0.97	-
	60-75	156.33	8.07	5.23	3.73	1.23	61.90	56.13	43.43	0.77	-
	75-90	165.00	8.03	4.89	5.00	1.50	52.77	47.93	33.73	0.77	-
30	0 -15	78.67	7.73	1.58	2.13	0.63	14.43	14.87	11.57	19.00	13.47
	15-30	99.00	7.50	5.51	9.80	2.97	55.97	53.13	28.17	12.60	-
	30-45	104.00	7.03	7.29	13.77	3.97	71.37	70.40	26.10	8.40	-
	45-60	123.67	7.40	6.84	7.27	2.37	72.77	70.20	35.13	4.40	-
	60-75	120.00	6.83	9.06	16.77	4.53	88.77	82.37	31.63	4.57	-
	75-90	129.00	7.37	9.64	17.17	4.73	105.30	114.10	36.63	2.23	-

[1] Means are of 3 samples.

Table 9. Means of analyses performed on plot samples using the disc method in 1984.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	99.67	8.07	3.77	2.67	0.93	45.10	34.60	33.20	3.57	2.93
	15-30	123.00	8.03	5.72	4.07	1.53	65.27	60.10	39.17	1.67	-
	30-45	126.33	8.07	6.56	4.50	1.50	85.33	70.27	51.80	1.40	-
	45-60	135.67	8.17	5.40	3.50	1.13	63.03	57.50	45.00	1.37	-
	60-75	150.00	8.20	5.49	3.33	1.13	65.10	54.47	47.70	0.73	-
	75-90	171.67	8.20	3.79	2.10	0.80	42.77	32.47	41.20	0.50	-
20	0 -15	96.67	8.07	4.22	2.90	1.23	51.10	36.60	37.47	5.33	3.67
	15-30	130.33	8.07	4.18	3.13	1.23	48.73	43.67	36.33	3.10	-
	30-45	141.33	8.07	4.09	2.87	1.13	47.60	43.27	38.33	2.30	-
	45-60	152.67	8.17	4.53	2.77	1.13	51.97	48.10	39.73	1.07	-
	60-75	150.00	8.13	4.22	2.43	1.07	49.27	40.80	43.73	1.00	-
	75-90	142.33	8.17	4.25	2.50	0.97	50.53	45.07	41.10	0.70	-
30	0 -15	75.00	7.53	2.95	5.97	1.53	32.00	32.07	15.30	7.97	12.67
	15-30	85.33	7.73	7.02	12.77	3.23	78.43	78.23	34.27	4.73	-
	30-45	106.67	7.97	5.93	6.00	1.83	69.30	61.57	39.27	3.07	-
	45-60	119.67	7.67	6.74	7.60	2.50	78.07	83.40	36.27	1.67	-
	60-75	116.00	7.43	7.32	11.13	4.07	83.13	83.37	34.27	1.53	-
	75-90	105.67	7.13	6.76	8.83	4.13	76.23	73.37	37.97	0.97	-

[1] Means are of 3 samples.

Table 10. Means of analyses performed on plot samples using the disc method in 1985.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	94.33	7.87	5.52	8.47	2.57	65.00	64.53	29.93	3.75	6.37
	15-30	112.33	7.90	6.92	7.50	2.83	89.20	80.90	40.40	1.57	-
	30-45	146.00	8.10	4.85	2.77	1.23	58.30	51.67	40.13	0.90	-
	45-60	160.33	8.17	3.61	1.43	0.67	43.30	32.43	44.60	0.65	-
	60-75	172.33	8.20	2.43	0.87	0.33	27.40	26.67	37.70	0.75	-
	75-90	171.00	8.20	3.10	1.00	0.37	35.73	32.70	44.77	0.55	-
20	0 -15	92.67	7.87	4.19	5.57	1.70	49.63	35.30	33.60	5.31	5.03
	15-30	133.67	7.97	5.69	7.53	2.47	64.30	55.67	38.23	1.76	-
	30-45	158.67	7.90	4.93	8.83	2.97	55.13	48.87	35.07	1.64	-
	45-60	158.67	7.57	5.84	9.87	3.47	71.13	62.13	35.93	2.31	-
	60-75	158.33	7.63	4.54	8.33	2.80	49.90	44.70	31.53	1.35	-
	75-90	149.33	7.47	5.19	8.33	2.70	56.03	54.83	38.17	0.43	-
30	0 -15	79.33	7.67	3.22	4.00	1.20	33.13	30.63	21.30	8.27	19.03
	15-30	122.33	7.87	6.96	10.10	2.83	79.13	70.00	35.87	2.52	-
	30-45	146.33	7.97	4.92	4.20	1.30	56.17	48.03	34.47	1.19	-
	45-60	151.00	7.93	4.74	4.10	1.30	52.20	44.90	32.40	1.11	-
	60-75	150.00	8.07	4.26	2.97	1.13	48.53	39.17	37.70	0.61	-
	75-90	143.33	8.07	4.32	2.47	0.93	50.63	42.73	42.37	0.49	-

[1] Means of 3 samples.

Table 11. Means of analyses performed on plot samples using the chisel plow method in 1983.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	131.33	8.00	5.22	3.57	1.23	63.33	59.07	41.03	4.47	4.77
	15-30	151.67	8.03	4.78	2.93	1.03	53.87	54.07	40.33	2.30	-
	30-45	172.33	8.17	2.85	1.03	0.40	30.43	29.47	35.70	1.20	-
	45-60	173.33	8.17	2.16	0.70	0.30	20.97	19.17	31.70	1.17	-
	60-75	171.67	8.23	2.39	0.70	0.27	25.27	23.30	36.77	1.20	-
	75-90	184.00	8.20	2.64	0.90	0.30	28.57	26.87	37.67	1.00	-
20	0 -15	80.00	7.90	3.07	4.77	1.43	31.27	27.07	20.80	7.53	4.77
	15-30	122.33	7.97	5.94	7.43	2.03	65.63	61.37	40.13	3.87	-
	30-45	148.33	8.10	4.04	1.90	0.70	45.33	40.83	41.30	2.30	-
	45-60	158.67	8.17	4.75	2.93	1.20	52.83	53.43	42.17	1.20	-
	60-75	169.00	7.97	5.51	5.40	1.97	60.73	61.13	39.13	1.43	-
	75-90	154.33	7.90	5.91	7.57	3.03	65.37	69.10	33.83	1.10	-
30	0 -15	65.67	7.57	1.13	1.93	0.60	9.03	10.53	8.27	14.30	8.37
	15-30	67.33	7.63	1.54	1.13	0.40	14.90	15.10	16.97	16.67	-
	30-45	115.33	8.03	5.08	2.83	1.07	56.43	49.40	40.87	5.47	-
	45-60	122.00	8.03	6.65	4.07	1.73	78.17	73.00	44.23	1.97	-
	60-75	126.00	7.90	6.25	6.83	2.47	68.50	63.43	36.50	2.67	-
	75-90	130.00	7.73	6.25	9.60	3.33	64.83	56.90	34.40	2.60	-

[1] Means of 3 samples.

Table 12. Means of analyses performed on plot samples using the chisel plow method in 1984.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	102.67	7.87	6.34	7.83	2.50	71.03	69.37	32.33	4.07	5.00
	15-30	115.67	7.40	8.77	11.83	5.33	109.20	109.20	39.60	2.40	-
	30-45	118.00	7.87	7.82	11.07	3.60	99.67	91.43	39.97	1.40	-
	45-60	141.67	8.13	5.38	3.43	1.43	63.97	55.93	42.13	1.50	-
	60-75	145.33	8.17	4.78	3.23	1.57	56.70	49.37	37.47	0.87	-
	75-90	145.67	8.20	4.49	2.67	1.07	51.73	46.53	38.93	0.83	-
20	0 -15	82.67	7.97	3.48	2.40	0.77	39.93	28.33	31.33	4.77	3.50
	15-30	132.33	8.10	2.90	1.77	0.53	34.83	25.40	32.90	2.47	-
	30-45	141.00	8.17	4.34	2.47	0.83	52.53	40.40	39.03	1.70	-
	45-60	154.67	8.27	4.89	3.27	1.13	61.17	50.53	40.73	1.43	-
	60-75	163.33	8.27	4.55	3.07	0.93	55.87	44.97	38.20	1.17	-
	75-90	170.33	8.30	4.14	2.17	0.57	52.00	43.67	43.53	0.87	-
30	0 -15	62.00	7.53	1.41	1.87	0.57	14.87	5.30	12.30	5.90	6.23
	15-30	90.67	8.03	2.73	1.87	0.67	31.23	23.30	26.33	3.07	-
	30-45	110.00	8.10	2.86	1.67	0.63	32.30	23.47	30.20	3.33	-
	45-60	112.00	8.13	4.26	2.00	0.80	51.17	45.30	42.13	2.33	-
	60-75	140.00	8.23	3.81	1.40	0.50	46.97	35.33	48.23	1.33	-
	75-90	157.67	8.30	2.57	0.93	0.27	30.37	22.90	41.00	1.17	-

[1] Means of 3 samples.

Table 13. Means of analyses performed on plot samples using the chisel plow method in 1985.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	135.67	8.03	4.78	4.50	1.47	50.87	42.23	32.13	3.11	8.50
	15-30	147.67	8.03	6.73	7.43	2.47	79.67	63.80	37.00	0.84	-
	30-45	159.33	8.10	5.11	4.60	1.70	50.17	47.60	32.50	0.81	-
	45-60	139.33	7.93	5.99	10.00	2.90	57.57	56.13	29.00	0.59	-
	60-75	157.33	8.13	4.24	3.67	1.23	43.50	36.47	32.93	1.29	-
	75-90	158.33	8.07	4.12	2.93	1.10	44.90	40.83	34.70	1.42	-
20	0 -15	100.00	7.97	3.08	2.77	1.47	34.70	27.93	28.60	1.61	4.53
	15-30	148.67	8.00	5.02	10.03	3.37	55.67	70.87	25.87	1.14	-
	30-45	166.67	8.13	4.99	6.90	2.90	56.70	51.83	27.27	0.87	-
	45-60	160.00	8.03	4.82	4.77	1.60	58.47	46.17	38.77	0.53	-
	60-75	156.33	8.17	4.80	2.23	0.90	57.30	48.73	46.97	0.61	-
	75-90	153.00	8.17	5.02	2.47	1.00	58.47	49.27	46.17	0.78	-
30	0 -15	78.33	7.67	2.77	2.30	0.93	29.40	22.97	21.27	4.30	7.43
	15-30	86.67	7.83	2.77	3.23	1.00	27.33	26.50	18.43	4.03	-
	30-45	102.67	8.03	4.53	4.00	1.30	48.30	45.50	31.97	2.38	-
	45-60	125.33	7.97	5.09	3.93	1.27	54.40	51.77	47.80	2.21	-
	60-75	132.00	7.97	5.93	4.73	1.57	63.03	59.90	36.40	0.87	-
	75-90	139.33	7.97	4.87	5.93	1.67	50.60	50.30	28.90	0.92	-

[1] Means of 3 samples.

Table 14. Means of analyses performed on plot samples using the subsoiler method in 1983.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	133.67	7.97	5.20	3.03	1.43	58.13	55.30	39.37	2.57	2.53
	15-30	143.33	8.03	4.92	2.80	1.10	52.77	50.93	39.03	1.13	-
	30-45	151.33	7.93	5.45	4.17	1.73	62.17	61.07	40.47	1.17	-
	45-60	136.33	8.03	4.91	2.43	1.10	55.80	52.73	42.17	1.03	-
	60-75	147.67	7.97	4.00	1.67	0.87	40.87	38.33	38.90	1.17	-
	75-90	149.67	8.03	4.49	1.60	0.93	49.00	47.80	44.10	1.20	-
20	0 -15	104.00	7.83	5.47	5.60	2.07	59.37	63.13	27.60	8.33	3.63
	15-30	123.00	7.90	5.48	8.30	2.53	58.13	53.00	30.53	2.77	-
	30-45	136.00	7.57	7.41	9.23	3.43	85.83	91.80	39.97	1.20	-
	45-60	149.67	8.00	8.66	4.53	2.37	110.37	107.80	58.27	0.77	-
	60-75	156.67	8.07	5.72	2.80	1.20	64.20	62.93	44.77	0.77	-
	75-90	140.67	7.67	7.61	9.30	3.73	81.73	87.83	38.50	0.90	-
30	0 -15	71.67	7.50	4.72	1.80	0.60	16.13	17.30	15.80	26.97	11.03
	15-30	95.67	7.83	2.83	1.77	0.67	32.40	32.20	28.77	19.90	-
	30-45	112.33	7.97	5.37	3.80	1.47	57.73	55.50	36.80	4.17	-
	45-60	129.67	7.50	7.14	10.10	4.13	77.33	86.63	34.50	3.53	-
	60-75	143.67	7.87	5.88	8.33	2.57	63.20	69.97	32.70	1.60	-
	75-90	154.00	7.83	4.81	5.73	2.23	49.53	55.07	31.67	0.87	-

[1] Means of 3 samples.

Table 15. Means of analyses performed on plot samples using the subsoiler method in 1984.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	90.67	8.07	3.22	2.67	0.70	38.53	29.37	29.97	5.07	3.03
	15-30	105.33	8.03	4.20	3.60	1.00	50.40	43.87	36.87	2.83	-
	30-45	130.67	8.10	6.30	4.27	1.37	71.47	64.50	47.70	1.80	-
	45-60	131.67	8.00	6.90	7.23	2.30	110.23	85.17	54.10	1.13	-
	60-75	144.00	7.97	6.63	5.77	2.37	106.03	83.97	55.40	1.03	-
	75-90	140.00	8.07	4.68	2.43	0.80	55.90	47.37	46.53	0.77	-
20	0 -15	95.33	7.83	4.12	3.70	1.17	47.80	40.63	30.80	4.90	6.37
	15-30	125.00	7.83	7.43	7.80	2.50	83.10	80.43	36.50	2.07	-
	30-45	134.00	7.80	7.60	8.37	2.90	85.37	85.17	40.43	1.27	-
	45-60	133.33	7.70	7.93	10.20	3.40	88.87	91.90	42.73	1.30	-
	60-75	123.67	6.73	6.53	9.13	3.50	67.67	67.27	37.60	1.43	-
	75-90	118.00	6.57	6.94	10.40	5.50	66.87	74.07	34.23	2.00	-
30	0 -15	91.00	7.37	1.84	1.30	0.47	21.33	15.30	19.83	9.77	10.20
	15-30	86.33	7.53	1.68	0.87	0.33	18.93	11.73	22.83	10.50	-
	30-45	82.33	7.73	3.84	4.77	1.77	45.37	38.57	27.60	3.57	-
	45-60	106.00	7.90	4.06	3.50	1.43	47.93	40.30	31.73	2.27	-
	60-75	119.67	8.03	3.98	3.50	1.37	47.83	38.77	33.30	1.50	-
	75-90	118.33	8.03	4.21	3.53	1.37	51.07	43.03	36.47	1.87	-

[1] Means of 3 samples.

Table 16. Means of analyses performed on plot samples using the subsoiler method in 1985.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	102.00	8.07	3.50	2.00	0.80	43.70	30.93	37.10	2.43	6.77
	15-30	140.67	8.20	3.59	1.43	0.63	44.03	33.47	43.93	1.72	-
	30-45	146.67	8.17	4.13	2.20	0.97	50.90	41.70	41.67	1.26	-
	45-60	143.33	8.10	3.88	2.37	1.00	44.33	37.53	36.27	1.29	-
	60-75	154.33	8.17	4.12	3.17	1.83	43.30	33.20	32.40	0.92	-
	75-90	148.33	8.20	3.04	1.50	0.60	30.77	27.93	32.60	0.81	-
20	0 -15	95.00	7.83	2.87	2.17	0.77	31.27	18.47	26.70	3.09	9.13
	15-30	119.33	8.07	3.82	2.00	0.77	41.87	36.17	35.33	1.38	-
	30-45	141.67	8.03	3.99	2.47	0.63	44.30	38.13	36.90	1.25	-
	45-60	164.33	8.00	4.33	3.30	1.33	47.23	31.23	32.13	0.66	-
	60-75	174.67	8.07	3.76	1.67	0.83	41.87	30.53	38.80	0.62	-
	75-90	179.67	8.13	4.27	2.40	1.30	47.63	44.57	45.57	0.73	-
30	0 -15	62.33	7.40	1.83	1.43	0.50	18.37	15.50	18.27	12.09	17.03
	15-30	103.67	7.83	3.17	1.67	0.70	31.87	33.03	29.63	11.55	-
	30-45	133.67	8.07	4.48	3.27	1.80	44.87	42.70	31.27	2.41	-
	45-60	141.33	8.00	3.92	2.40	0.83	42.13	35.50	35.13	1.68	-
	60-75	150.67	8.13	3.50	1.57	0.57	36.10	33.57	34.83	2.70	-
	75-90	153.67	8.17	3.60	1.57	0.60	38.20	32.93	37.17	1.47	-

[1] Means of 3 samples.

Table 17. Means of analyses performed on plot samples using the blanket method in 1983.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	140.33	8.10	4.82	2.10	0.77	55.87	53.77	47.13	6.80	3.90
	15-30	155.67	8.17	4.63	2.20	0.90	52.17	50.73	42.77	1.70	-
	30-45	170.67	8.20	4.04	1.80	0.73	44.87	43.03	39.93	0.87	-
	45-60	192.00	8.23	3.60	1.67	0.70	41.50	41.73	39.10	1.13	-
	60-75	175.00	8.20	4.25	2.10	0.73	47.47	44.40	41.60	0.83	-
	75-90	166.33	8.17	3.54	1.63	0.67	36.97	36.80	34.30	1.23	-
20	0 -15	75.00	7.53	2.66	2.27	0.73	29.27	29.87	23.07	23.03	13.77
	15-30	132.33	8.00	3.22	1.63	0.63	32.77	31.80	32.73	4.93	-
	30-45	150.00	8.00	3.00	1.50	0.50	31.07	29.90	33.30	3.13	-
	45-60	172.00	8.13	3.31	1.40	0.47	34.60	32.20	38.60	1.73	-
	60-75	169.00	8.07	4.42	2.70	0.77	53.03	53.00	44.83	0.80	-
	75-90	164.67	8.10	5.01	3.50	1.00	52.73	53.90	36.63	1.03	-
30	0 -15	82.67	7.67	2.38	1.77	0.73	25.40	24.13	21.77	24.00	11.80
	15-30	131.00	7.90	6.94	4.80	2.13	76.93	73.67	41.77	6.93	-
	30-45	130.67	7.70	8.59	10.70	3.63	91.63	91.33	39.37	4.60	-
	45-60	145.67	7.93	5.98	3.93	1.37	68.53	69.07	42.93	3.17	-
	60-75	147.67	7.97	6.26	3.40	1.30	73.63	73.10	47.93	1.73	-
	75-90	132.33	7.97	6.38	4.07	1.53	70.00	70.53	42.80	2.57	-

[1] Means of 3 samples.

Table 18. Means of analyses performed on plot samples using the blanket method in 1984.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	132.67	7.97	3.63	2.13	1.00	44.90	34.47	37.53	2.43	5.30
	15-30	173.67	8.13	3.46	1.97	0.73	43.10	33.73	38.93	1.87	-
	30-45	155.67	8.17	3.24	1.90	0.63	39.40	30.10	35.50	1.57	-
	45-60	164.33	8.20	3.32	1.77	0.67	40.80	30.90	38.30	0.93	-
	60-75	157.33	8.23	3.34	1.40	0.57	40.17	34.13	40.83	0.87	-
	75-90	142.33	8.17	4.23	2.03	0.73	52.30	44.37	46.00	1.37	-
20	0 -15	87.33	7.93	4.00	1.53	1.10	46.70	36.60	38.70	6.83	5.10
	15-30	121.00	8.13	4.93	2.73	1.07	60.77	50.10	46.43	5.00	-
	30-45	122.00	8.07	5.67	6.83	2.53	81.03	63.27	44.07	2.97	-
	45-60	130.00	8.13	5.46	5.43	2.07	79.87	57.73	46.80	2.10	-
	60-75	135.00	7.80	5.37	8.53	3.60	72.50	62.33	37.87	1.60	-
	75-90	126.67	7.77	5.99	9.63	3.77	60.83	61.97	40.43	1.00	-
30	0 -15	74.33	7.60	5.71	7.37	2.63	71.70	63.83	29.87	11.70	7.03
	15-30	86.00	7.77	5.62	8.03	2.87	78.73	63.97	33.33	11.30	-
	30-45	88.33	7.80	6.48	8.13	2.87	93.13	75.10	37.97	6.73	-
	45-60	105.33	8.00	6.04	5.93	2.17	87.03	66.67	45.63	2.70	-
	60-75	117.67	7.97	5.97	5.13	1.97	88.07	64.97	50.73	1.80	-
	75-90	121.00	8.07	4.37	3.23	1.17	53.53	42.60	40.53	1.70	-

[1] Means of 3 samples.

Table 19. Means of analyses performed on piot samples using the blanket method in 1985.[1]

Ash (cm)	Depth (cm)	Sat. %	pH	EC (mS/cm)	Ca (me/L)	Mg (me/L)	Na (me/L)	SO4 (me/L)	SAR	B (ppm)	OM (%)
10	0 -15	116.67	7.80	5.15	6.53	1.97	54.37	45.47	29.83	2.90	12.07
	15-30	145.33	8.03	3.64	1.80	0.67	39.80	28.57	35.97	0.83	-
	30-45	156.33	8.03	3.68	1.80	0.67	37.73	30.13	34.37	1.74	-
	45-60	146.67	8.07	4.79	2.33	1.00	52.63	43.33	40.73	0.83	-
	60-75	150.33	8.10	4.68	2.13	0.97	48.43	42.17	38.20	1.92	-
	75-90	158.67	8.13	4.10	1.83	0.80	43.37	35.50	36.53	2.31	-
20	0 -15	99.67	7.43	6.08	10.07	3.07	60.63	58.80	31.13	7.75	12.60
	15-30	126.67	8.00	4.73	3.87	1.30	48.73	42.83	35.63	1.41	-
	30-45	149.67	8.03	5.34	5.13	1.77	55.80	52.17	38.17	1.22	-
	45-60	152.33	7.97	5.04	4.20	1.57	52.87	47.53	38.17	1.06	-
	60-75	154.67	7.80	5.02	5.07	2.03	50.03	40.87	36.83	0.84	-
	75-90	149.33	8.10	3.52	1.83	0.77	35.83	29.40	37.23	0.68	-
30	0 -15	92.00	7.53	1.59	2.27	0.67	14.60	10.17	13.03	8.52	17.43
	15-30	114.67	7.73	5.48	7.93	2.40	59.90	63.33	30.40	3.83	-
	30-45	137.67	7.40	6.42	10.63	3.90	81.33	68.07	38.13	1.00	-
	45-60	140.00	7.00	6.65	8.90	3.70	93.37	68.00	44.93	0.61	-
	60-75	149.67	7.27	6.80	9.97	4.00	84.97	73.10	41.43	0.54	-
	75-90	135.67	6.80	6.59	8.87	4.07	93.43	68.47	44.20	0.71	-

[1] Means of 3 samples.

Table 20. Means of plant tissue chemistry and yield in 1983.[1]

Method	Ash (cm)	Yield (kg/200m sqr.)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Disc	10	28.67	1.84	0.11	1.08	0.97	0.18	70.13	24.00	820.00	70.67	48.33
	20	35.97	1.45	0.08	1.10	0.76	0.14	49.70	25.67	563.67	60.33	39.00
	30	43.90	1.41	0.09	0.98	0.82	0.14	39.87	15.33	360.33	31.00	28.67
Chisel Plow	10	14.47	1.63	0.11	1.09	0.87	0.16	52.83	23.33	634.00	77.00	43.33
	20	28.53	1.36	0.08	1.00	0.73	0.13	50.40	25.00	481.67	53.00	40.33
	30	47.97	1.40	0.08	1.09	0.93	0.15	42.43	12.33	339.67	31.33	25.00
Subsoiler	10	41.27	1.30	0.07	0.95	0.61	0.12	35.80	24.00	412.33	63.33	48.00
	20	38.77	1.65	0.13	1.00	0.82	0.17	58.70	24.00	773.67	64.00	44.67
	30	45.17	1.52	0.09	1.07	1.05	0.17	45.63	17.00	334.67	33.67	28.33
Blanket	10	28.40	1.38	0.09	0.90	0.60	0.14	42.87	30.33	519.00	56.67	47.33
	20	24.67	1.51	0.08	0.97	0.71	0.16	67.37	24.33	906.33	73.33	43.67
	30	36.07	1.61	0.09	1.08	0.92	0.15	45.90	18.67	377.00	43.33	34.67

[1] Means of 3 samples.

Table 21. Means of plant tissue chemistry and yield in 1984.[1]

Method	Ash (cm)	Yield (kg/200m sqr.)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Disc	10	15.27	1.71	0.10	1.57	0.59	0.12	43.33	11.33	340.67	51.33	37.00
	20	18.73	1.83	0.11	1.77	0.64	0.14	73.33	9.33	283.00	34.33	38.33
	30	29.33	1.62	0.11	1.72	0.68	0.13	60.00	11.33	151.00	25.33	30.33
Chisel Plow	10	12.20	1.66	0.12	1.61	0.49	0.12	48.67	5.67	296.67	42.00	39.00
	20	20.67	1.82	0.12	1.75	0.64	0.13	61.33	5.33	251.33	34.00	35.67
	30	25.27	1.78	0.11	1.69	0.63	0.13	69.67	5.67	264.67	30.00	37.67
Subsoiler	10	17.43	1.70	0.09	1.60	0.55	0.12	41.33	5.33	238.67	43.33	39.67
	20	29.30	1.54	0.10	1.55	0.46	0.11	36.33	7.67	138.33	28.33	31.33
	30	32.27	1.78	0.10	1.70	0.76	0.14	54.00	8.33	278.00	29.33	34.33
Blanket	10	14.87	1.61	0.10	1.51	0.48	0.11	33.33	10.67	252.00	32.67	36.00
	20	20.73	1.57	0.10	1.56	0.56	0.11	55.33	10.00	291.33	36.00	34.67
	30	20.03	1.97	0.13	1.88	0.77	0.15	54.00	5.33	242.00	30.67	33.00

[1] Means of 3 samples.

Table 22. Means of plant tissue chemistry and yield in 1985. [1]

Method	Ash (cm)	Yield (kg/200m sqr.)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	B (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Disc	10	18.96	1.80	0.11	1.20	0.63	0.12	42.67	4.17	306.33	31.50	42.03
	20	24.92	1.67	0.11	1.01	0.52	0.12	49.67	3.37	228.00	27.93	31.07
	30	36.30	1.56	0.12	0.86	0.56	0.10	48.00	2.53	149.00	16.00	21.83
Chisel Plow	10	16.26	1.69	0.12	1.17	0.51	0.12	35.33	4.77	429.33	35.17	38.87
	20	31.37	1.57	0.10	1.00	0.49	0.11	41.67	3.57	183.00	25.67	31.60
	30	38.94	1.52	0.12	1.01	0.49	0.11	54.33	3.50	163.67	22.53	27.80
Subsoiler	10	26.60	1.79	0.10	1.08	0.59	0.11	36.67	4.40	276.67	38.73	40.10
	20	36.35	1.74	0.12	1.04	0.57	0.11	40.00	3.47	203.00	25.00	31.27
	30	39.12	1.85	0.13	1.09	0.64	0.11	61.67	3.23	204.67	23.87	29.20
Blanket	10	22.03	1.80	0.14	1.16	0.55	0.12	37.33	11.13	337.67	29.47	324.77
	20	27.64	1.70	0.11	1.12	0.53	0.12	52.00	3.57	226.00	29.97	127.03
	30	41.29	1.76	0.13	1.18	0.60	0.12	52.33	3.47	203.33	21.83	105.97

[1] Means of 3 samples.

Table 23. Mean monthly soil % MC readings for the disc method in 1983.[1]

Ash (cm)	Depth (cm)	Summer (83)	Fall (83)	Winter (83/84)
10	0 - 15	30.95	27.26	23.79
	15 - 30	36.03	28.43	26.87
	30 - 45	39.06	32.59	29.37
	45 - 60	40.91	36.51	32.21
	60 - 75	41.07	38.91	34.62
	75 - 90	41.03	40.12	36.05
	90 -105	40.23	39.66	36.30
	105-120	39.94	40.01	36.32
20	0 - 15	25.94	21.21	17.84
	15 - 30	31.99	26.14	22.61
	30 - 45	37.02	31.79	27.15
	45 - 60	37.98	35.51	30.76
	60 - 75	39.63	38.39	33.32
	75 - 90	39.01	38.59	34.57
	90 -105	38.83	38.98	35.33
	105-120	40.55	40.64	36.22
30	0 - 15	26.12	21.31	18.27
	15 - 30	29.74	28.04	23.62
	30 - 45	33.40	33.07	28.79
	45 - 60	36.14	36.71	32.27
	60 - 75	38.27	38.89	34.57
	75 - 90	39.79	40.20	35.56
	90 -105	39.14	37.28	35.27
	105-120	39.01	39.46	35.99

[1] Means of 24 readings.

Table 24. Mean monthly soil % MC readings for the disc method in 1984.[1]

Ash (cm)	Depth (cm)	Spring (84)	Summer (84)	Fall (84)	Winter (84/85)
10	0 - 15	17.90	8.42	19.75	29.03
	15 - 30	40.83	23.65	32.73	34.18
	30 - 45	30.00	27.78	34.03	35.22
	45 - 60	30.13	29.22	35.00	35.25
	60 - 75	33.97	32.28	35.07	35.33
	75 - 90	35.87	35.40	36.37	35.73
	90 -105	36.87	36.90	37.02	36.53
	105-120	36.90	36.87	37.98	37.47
20	0 - 15	11.80	7.15	18.35	23.23
	15 - 30	21.73	20.33	26.68	28.85
	30 - 45	24.53	23.05	27.27	28.03
	45 - 60	28.90	28.50	29.05	29.35
	60 - 75	31.83	30.90	30.17	30.45
	75 - 90	34.80	33.70	33.10	32.70
	90 -105	36.27	35.83	33.63	33.78
	105-120	36.10	37.42	35.58	35.12
30	0 - 15	11.63	4.83	12.92	20.63
	15 - 30	20.60	15.00	23.13	27.08
	30 - 45	25.80	24.87	26.68	28.38
	45 - 60	29.57	29.18	29.28	30.87
	60 - 75	33.10	32.40	31.97	33.05
	75 - 90	35.63	36.33	35.58	35.82
	90 -105	37.10	38.82	38.05	36.88
	105-120	37.10	38.42	38.17	36.90

[1] Means of 24 readings.

Table 25. Mean monthly soil % MC readings for the disc method in 1985.[1]

Ash (cm)	Depth (cm)	Spring (85)	Summer (85)	Fall (85)
10	0 - 15	22.54	13.33	12.12
	15 - 30	34.45	30.51	28.62
	30 - 45	36.22	33.62	31.56
	45 - 60	35.93	34.32	32.25
	60 - 75	36.21	35.29	33.85
	75 - 90	38.31	36.12	34.50
	90 -105	39.49	36.56	34.86
	105-120	39.98	37.11	36.09
20	0 - 15	20.66	8.48	7.10
	15 - 30	31.12	24.24	22.89
	30 - 45	29.76	26.54	26.87
	45 - 60	30.95	28.89	29.64
	60 - 75	33.41	30.09	29.97
	75 - 90	35.43	32.25	31.17
	90 -105	35.17	32.64	32.19
	105-120	36.88	34.74	32.68
30	0 - 15	15.65	4.18	6.15
	15 - 30	30.27	22.92	22.30
	30 - 45	28.45	26.83	25.10
	45 - 60	30.77	29.10	27.51
	60 - 75	33.61	31.73	29.77
	75 - 90	36.36	34.76	32.20
	90 -105	38.33	36.65	34.17
	105-120	38.88	36.88	34.98

[1] Means of 24 readings.

Table 26. Mean monthly soil % MC readings for the chisel plow method in 1983.[1]

Ash (cm)	Depth (cm)	Summer (83)	Fall (83)	Winter (83/84)
10	0 - 15	30.09	27.86	26.26
	15 - 30	35.29	30.88	30.57
	30 - 45	36.95	31.27	31.51
	45 - 60	35.56	32.53	31.48
	60 - 75	36.44	33.31	31.42
	75 - 90	34.10	34.59	31.96
	90 -105	34.85	35.88	32.43
	105-120	36.03	36.54	33.27
20	0 - 15	31.42	29.26	21.27
	15 - 30	34.14	31.26	28.42
	30 - 45	35.47	31.85	30.27
	45 - 60	36.34	33.37	31.62
	60 - 75	37.59	36.02	33.05
	75 - 90	37.54	37.09	34.27
	90 -105	38.67	39.21	35.33
	105-120	41.17	41.77	36.82
30	0 - 15	18.57	17.16	14.81
	15 - 30	33.83	27.11	21.51
	30 - 45	35.24	29.32	27.43
	45 - 60	34.10	28.81	27.68
	60 - 75	34.63	33.42	29.65
	75 - 90	35.37	35.86	31.35
	90 -105	39.84	39.78	34.51
	105-120	43.01	43.69	37.85

[1] Means of 24 readings.

Table 27. Mean monthly soil % MC readings for the chisel plow method in 1984.[1]

Ash (cm)	Depth (cm)	Spring (84)	Summer (84)	Fall (84)	Winter (84/85)
10	0 - 15	20.87	11.47	18.32	26.97
	15 - 30	30.23	24.83	30.37	35.13
	30 - 45	33.20	29.95	33.60	34.73
	45 - 60	33.47	31.00	33.03	34.30
	60 - 75	32.20	31.63	33.13	34.15
	75 - 90	32.77	32.95	34.37	34.93
	90 -105	32.60	34.18	35.73	35.88
	105-120	33.40	35.83	36.78	36.95
20	0 - 15	13.17	6.40	14.82	19.32
	15 - 30	27.73	23.67	27.75	29.53
	30 - 45	30.90	28.78	30.40	31.05
	45 - 60	32.27	30.92	30.25	31.55
	60 - 75	33.00	31.60	31.25	32.22
	75 - 90	34.83	34.22	33.32	34.30
	90 -105	35.53	35.33	35.40	36.23
	105-120	35.60	36.52	36.77	36.97
30	0 - 15	9.07	3.90	10.10	18.12
	15 - 30	16.07	11.05	18.85	23.92
	30 - 45	26.40	24.73	28.05	28.95
	45 - 60	28.40	28.07	29.97	28.53
	60 - 75	28.00	28.55	28.15	28.03
	75 - 90	28.73	29.53	28.80	29.97
	90 -105	31.93	31.77	31.53	32.55
	105-120	35.43	36.68	37.17	36.78

[1] Means of 24 readings.

Table 28. Mean monthly soil % MC readings for the chisel plow method in 1985.[1]

Ash (cm)	Depth (cm)	Spring (85)	Summer (85)	Fall (85)
10	0 - 15	23.11	12.56	7.63
	15 - 30	34.69	29.07	20.83
	30 - 45	36.83	33.79	29.53
	45 - 60	36.31	34.14	31.52
	60 - 75	35.12	33.44	31.67
	75 - 90	36.29	34.42	34.26
	90 -105	37.42	35.71	35.84
	105-120	38.51	36.89	36.34
20	0 - 15	18.59	7.39	8.72
	15 - 30	30.77	26.49	21.84
	30 - 45	32.48	30.34	31.14
	45 - 60	32.82	31.00	31.06
	60 - 75	33.16	31.57	31.64
	75 - 90	35.89	34.15	33.05
	90 -105	38.04	35.55	34.06
	105-120	39.27	36.98	35.12
30	0 - 15	12.67	-0.39	0.74
	15 - 30	30.09	16.54	15.48
	30 - 45	32.43	27.67	27.56
	45 - 60	31.83	27.92	27.65
	60 - 75	30.07	27.12	26.59
	75 - 90	30.88	28.49	27.71
	90 -105	33.97	30.95	29.89
	105-120	38.20	35.39	34.54

[1] Means of 24 readings.

Table 29. Mean monthly soil % MC readings for the subsoiler method in 1983.[1]

Ash (cm)	Depth (cm)	Summer (83)	Fall (83)	Winter (83/84)
10	0 - 15	31.91	24.11	21.40
	15 - 30	37.61	28.83	27.09
	30 - 45	39.14	31.26	30.04
	45 - 60	38.91	33.80	31.62
	60 - 75	38.54	35.57	32.77
	75 - 90	38.59	35.54	33.07
	90 -105	37.13	36.23	33.47
	105-120	39.21	37.01	33.69
20	0 - 15	30.37	24.96	19.69
	15 - 30	41.16	33.61	26.99
	30 - 45	40.45	34.51	31.10
	45 - 60	41.73	37.65	33.36
	60 - 75	41.39	37.95	34.45
	75 - 90	40.44	38.75	35.33
	90 -105	39.98	39.18	35.43
	105-120	41.74	42.22	37.20
30	0 - 15	27.04	18.01	14.07
	15 - 30	41.54	34.10	23.74
	30 - 45	40.21	38.63	32.74
	45 - 60	40.49	39.98	36.43
	60 - 75	39.08	37.17	35.00
	75 - 90	36.73	36.18	34.51
	90 -105	37.07	36.32	33.63
	105-120	37.38	37.21	34.07

[1] Means of 24 readings.

Table 30. Mean monthly soil % MC readings for the subsoiler method in 1984.[1]

Ash (cm)	Depth (cm)	Spring (84)	Summer (84)	Fall (84)	Winter (84/85)
10	0 - 15	13.40	6.57	14.15	25.52
	15 - 30	27.80	21.80	28.82	33.02
	30 - 45	32.57	30.52	34.75	35.23
	45 - 60	33.57	32.48	34.62	33.90
	60 - 75	33.50	32.70	32.97	33.42
	75 - 90	34.00	33.53	33.27	33.83
	90 -105	34.93	34.85	33.15	35.20
	105-120	33.97	34.48	34.58	35.28
20	0 - 15	11.43	6.30	17.85	21.20
	15 - 30	22.00	17.57	27.83	28.13
	30 - 45	30.33	26.40	32.23	33.83
	45 - 60	33.17	31.05	32.97	34.10
	60 - 75	34.20	33.20	34.02	35.28
	75 - 90	36.03	35.18	35.67	36.17
	90 -105	36.33	36.08	36.43	36.75
	105-120	36.50	37.58	38.07	37.55
30	0 - 15	9.77	4.88	11.35	17.75
	15 - 30	16.23	12.08	18.60	20.72
	30 - 45	29.50	26.15	28.62	31.90
	45 - 60	35.17	33.13	34.90	35.23
	60 - 75	37.00	36.17	37.17	36.78
	75 - 90	36.53	37.18	36.95	35.95
	90 -105	34.70	35.93	35.05	34.50
	105-120	34.33	36.53	36.38	35.20

[1] Means of 24 readings.

Table 31. Mean monthly soil % MC readings for the subsoiler method in 1985.[1]

Ash (cm)	Depth (cm)	Spring (85)	Summer (85)	Fall (85)
10	0 - 15	18.83	6.72	7.57
	15 - 30	37.77	28.06	23.99
	30 - 45	38.37	34.34	31.15
	45 - 60	36.59	34.22	32.97
	60 - 75	34.46	32.46	31.92
	75 - 90	35.10	32.61	32.02
	90 -105	36.06	33.76	32.09
	105-120	35.77	33.98	32.29
20	0 - 15	17.19	6.94	5.47
	15 - 30	31.15	23.00	21.23
	30 - 45	36.42	31.16	29.73
	45 - 60	35.52	32.45	32.74
	60 - 75	36.92	33.49	32.76
	75 - 90	38.16	35.04	34.45
	90 -105	38.80	35.56	34.51
	105-120	39.57	36.77	35.12
30	0 - 15	10.05	2.07	1.26
	15 - 30	26.74	16.81	16.90
	30 - 45	34.33	31.11	29.17
	45 - 60	37.17	32.48	31.05
	60 - 75	37.37	34.69	32.69
	75 - 90	37.41	34.08	32.79
	90 -105	35.87	32.55	33.41
	105-120	36.43	33.70	34.05

[1] Means of 24 readings.

Table 32. Mean monthly soil % MC readings for the blanket method in 1983.[1]

Ash (cm)	Depth (cm)	Summer (83)	Fall (83)	Winter (83/84)
10	0 - 15	33.27	24.79	23.37
	15 - 30	37.81	28.41	27.27
	30 - 45	38.15	31.37	28.90
	45 - 60	38.19	35.84	31.83
	60 - 75	37.18	35.24	31.98
	75 - 90	34.72	33.90	32.27
	90 -105	34.31	34.03	31.63
	105-120	33.76	33.87	31.32
20	0 - 15	32.47	28.42	24.12
	15 - 30	37.64	34.48	28.99
	30 - 45	38.23	35.98	32.19
	45 - 60	37.84	35.39	32.91
	60 - 75	37.63	35.36	32.87
	75 - 90	36.49	35.21	32.92
	90 -105	35.94	34.31	32.48
	105-120	34.71	34.39	32.56
30	0 - 15	24.67	19.43	16.01
	15 - 30	40.16	28.78	22.57
	30 - 45	44.66	34.33	29.54
	45 - 60	44.64	40.37	34.15
	60 - 75	44.94	43.16	36.97
	75 - 90	44.88	42.36	38.65
	90 -105	42.78	41.04	38.42
	105-120	42.81	42.57	38.03

[1] Means of 24 readings.

Table 33. Mean monthly soil % MC readings for the blanket method in 1984.[1]

Ash (cm)	Depth (cm)	Spring (84)	Summer (84)	Fall (84)	Winter (84/85)
10	0 - 15	17.97	12.07	25.03	34.85
	15 - 30	28.67	25.22	33.22	36.78
	30 - 45	32.00	30.03	36.47	36.70
	45 - 60	33.10	32.15	34.40	34.30
	60 - 75	32.47	32.88	32.68	33.33
	75 - 90	34.00	34.92	34.18	34.53
	90 -105	33.03	34.03	33.15	32.98
	105-120	32.30	33.45	32.85	32.45
20	0 - 15	17.00	6.33	14.60	23.58
	15 - 30	28.83	22.98	26.67	29.57
	30 - 45	32.37	30.62	31.48	32.23
	45 - 60	35.07	33.38	33.02	33.33
	60 - 75	35.33	33.97	33.22	33.48
	75 - 90	35.03	34.52	34.20	34.37
	90 -105	35.03	34.70	34.05	34.02
	105-120	35.13	34.58	33.75	34.18
30	0 - 15	8.90	5.08	9.78	17.25
	15 - 30	17.40	12.65	20.65	24.80
	30 - 45	27.33	24.28	30.48	33.47
	45 - 60	30.80	28.22	34.08	37.00
	60 - 75	34.97	31.75	36.95	37.63
	75 - 90	38.73	36.13	37.97	38.32
	90 -105	39.97	37.58	38.17	39.08
	105-120	39.33	39.65	39.55	38.90

[1] Means of 24 readings.

Table 34. Mean monthly soil % MC readings for the blanket method in 1985.[1]

Ash (cm)	Depth (cm)	Spring (85)	Summer (85)	Fall (85)
10	0 - 15	28.14	17.99	17.66
	15 - 30	37.84	33.01	31.53
	30 - 45	39.22	36.01	34.51
	45 - 60	36.63	34.33	32.67
	60 - 75	33.86	32.25	31.54
	75 - 90	35.42	33.34	32.83
	90 -105	34.70	32.31	31.52
	105-120	34.50	32.01	31.43
20	0 - 15	23.56	10.36	14.52
	15 - 30	32.92	26.27	28.40
	30 - 45	33.59	31.19	32.22
	45 - 60	34.50	32.42	32.15
	60 - 75	34.45	33.16	32.97
	75 - 90	35.72	33.94	33.38
	90 -105	33.49	33.62	32.44
	105-120	35.63	34.23	33.73
30	0 - 15	13.23	2.13	7.15
	15 - 30	30.56	16.85	25.88
	30 - 45	38.16	30.36	33.50
	45 - 60	39.80	34.86	33.69
	60 - 75	41.84	37.85	34.06
	75 - 90	42.66	38.51	34.41
	90 -105	40.91	37.23	36.40
	105-120	39.99	37.00	37.55

[1] Means of 24 readings.

Table 35. Soil strength measurements in 1985.[1]

Method	Rate (cm)	Soil Strength (bar)
Disc	10	0.34
	20	0.29
	30	0.22
Chisel Plow	10	0.32
	20	0.27
	30	0.23
Subsoiler	10	0.27
	20	0.22
	30	0.20
Blanket	10	0.25
	20	0.28
	30	0.20

1 Means of 453 readings.

Table 36. Split-plot ANOVA for soil variables.**

Source of Variation		Sat.%	pH	EC (mS/cm)	Ca	Mg	Na	SAR	SO_4 (me/L)	B (ppm)	OM (%)
					-----(me/L)------						
Method	disc	130	7.9	5.1	5.6	1.8	57.5	36	52.7	2.8	7.6
	chisel	133	8.0	4.5	4.0	1.4	50.2	35	45.2	2.6	5.9
	subsoiler	128	7.9	4.7	4.0	1.6	53.7	36	49.4	3.4	7.7
	blanket	136	7.9	4.8	4.3	1.6	56.7	38	49.4	3.6	9.9
Rate		*	*					*		*	*
	10 cm	144	8.1	4.6	3.3	1.2	53.5	39	47.3	1.7	5.3
	20 cm	137	7.9	4.9	4.8	1.7	55.1	37	50.3	2.4	6.3
	30 cm	114	7.8	4.8	5.3	1.8	55.1	33	50.0	5.2	11.8
Year		*								*	*
	1983	135	7.9	4.9	4.4	1.5	53.7	36	52.6	4.4	7.0
	1984	124	7.9	4.9	4.6	1.7	59.4	38	51.2	2.8	5.9
	1985	137	7.9	4.5	4.4	1.6	50.5	35	43.7	2.1	10.5
Depth		*	*	*			*	*	*	*	
(cm)	0-15	94	7.8	3.6	3.6	1.2	40.5	27	35.1	7.8	-
	15-30	121	7.9	4.8	4.9	1.7	54.6	35	50.2	4.5	-
	30-45	136	8.0	5.1	4.9	1.7	58.6	37	53.1	2.3	-
	30-60	143	8.0	5.2	4.6	1.7	61.6	40	55.1	1.5	-
	60-75	149	7.9	5.0	4.5	1.7	58.0	40	51.6	1.3	-
	75-90	148	7.9	4.8	4.4	1.7	53.6	39	49.9	1.2	-
Method x Rate											
Method x Year											
Method x Depth										*	
Rate x Year										*	
Rate x Depth		*		*	*	*	*	*	*	*	
Depth x Year										*	
M x R x Y											
M x D x Y		*									
R x D x Y								*			
M x R x D											
M x R x D											

* Significant at p<0.05.
** Values are mean values.

Table 37. Sat.% with depth for each method of ash application in 1984.

	Method			
Depth (cm)	Disc	Chisel Plow	Subsoiler	Blanket
0-15	90a	82a	92a	98a
15-30	113ab	113 b	106ab	127 b
30-45	125 bc	123 b	116 b	122 b
45-60	136 bc	136 bc	124 b	133 b
60-75	139 c	150 c	129 b	136 b
75-90	140 c	158 c	125 b	130 b

Means with same subscripts (a,b,c) are not significantly different at $p<0.05$.

Table 38. Summary of ANOVA and Tukey's tests for main effects on the plant variables.**

Source of variation	Yield (kg/200m^2)	N(%)	P(%)	K(%)	Ca(%)	Mg(%)	B(ppm)	Cu(ppm)	Fe(ppm)	Mn(ppm)	Zn(ppm)
method											
disc	28.0	1.7	0.1	1.3	0.7	0.1	53.0	11.9	356	38.7	35.2
chisel plow	26.2	1.6	0.1	1.3	0.6	0.1	50.7	9.9	338	39.0	35.5
subsoiler	34.0	1.7	0.1	1.2	0.7	0.1	45.6	10.8	318	38.8	36.3
blanket	26.2	1.7	0.1	1.3	0.6	0.1	48.9	13.1	373	39.3	87.5
rate	L*						L*	L*	L*	L*	
10 cm	21.4	1.7	0.1	1.2	0.6	0.1	43.4	13.3	405	47.7	65.4
20 cm	28.1	1.6	0.1	1.2	0.6	0.1	50.0	12.1	377	41.0	44.1
30 cm	36.3	1.7	0.1	1.3	0.7	0.1	52.3	8.9	256	28.2	36.4
year	*	*	*	*	*	*		*	*	*	
1983	34.5 a	1.5 b	0.0 b	1.1 b	0.8 a	0.2 a	50.1	22.0 a	544 a	54.8*	39.3
1984	21.3 b	1.7 a	0.1 a	1.7 a	0.6 b	0.1 b	52.6	8.0 b	252 b	34.8	35.6
1985	30.0 a	1.7 a	0.1 a	1.7 a	0.6 b	0.1 b	46.0	4.3 b	243 b	27.3	71.0
Method x Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Method x Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rate x Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
Method x Rate x Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Test for trends for rate											
Linear	*						*	*	*		
Quadratic	NS						NS	NS	NS		

* Significant at $p<0.05$.
NS Not Significant.
Means with same subscripts (a,b) are not significantly different at p 0.05.
L Significant linear trend at p 0.05.
** Values are mean values.

Table 39. Split-plot ANOVA for soil strength readings.**

Source of Variation	Soil Strength (bar)
Method	*
disc	0.28
chisel plow	0.27
subsoiler	0.23
blanket	0.24
Rate	*
10 cm	0.30
20 cm	0.26
30 cm	0.21
Depth (cm)	*
3.5	0.00
7	0.09
10.5	0.15
14	0.18
17.5	0.21
21	0.24
24.5	0.27
28	0.29
31.5	0.31
35	0.32
38.5	0.33
42	0.35
45.5	0.36
49	0.37
52.5	0.39
Method x Rate	NS
Method x Depth	*
Rate x Depth	*
Method x Rate x Depth	NS

* Significant at $p<0.05$.
NS Not Significant.
** Values are mean values.

Table 40. Split-plot ANOVA for moisture for bottom ash plots.

Source of variation	Summer 83	Fall 83	Winter 83/84	Spring 84	Summer 84	Fall 84	Winter 84/85	Spring 85	Summer 85	Fall 85
Method	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rate	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
Depth	*	*	*	*	*	*	*	*	*	*
Method x Ash	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth x Method	NS	NS	*	*	*	NS	NS	*	NS	*
Depth x Ash	*	*	*	*	*	*	*	*	*	*
Depth x Method x Ash	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at $p<0.05$.
NS Not Significant.

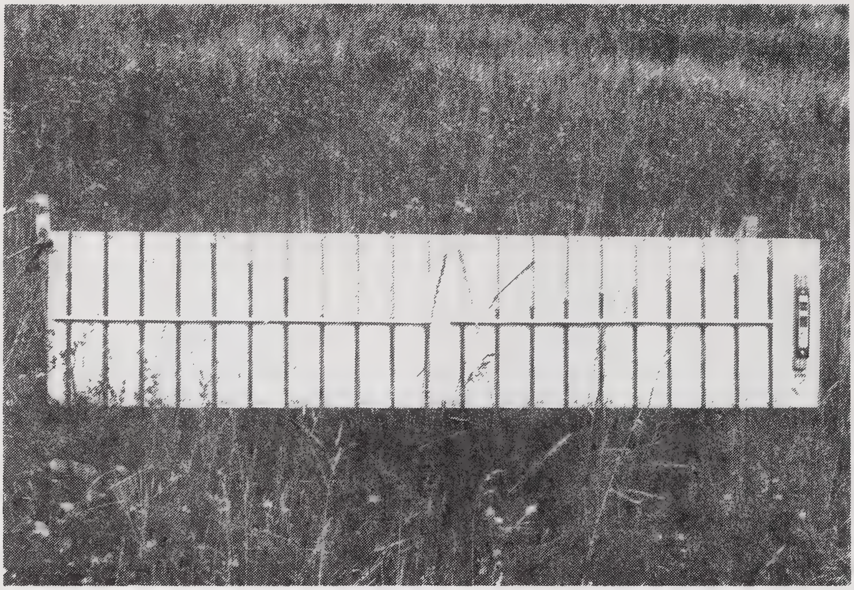

Figure 31. Erosion Board

Figure 32. Plot 25, slope 4, Smoky River

Figure 33. Slumping at base of slope 2, Tent Mountain

Figure 34. Plot 7, slope 4, Smoky River

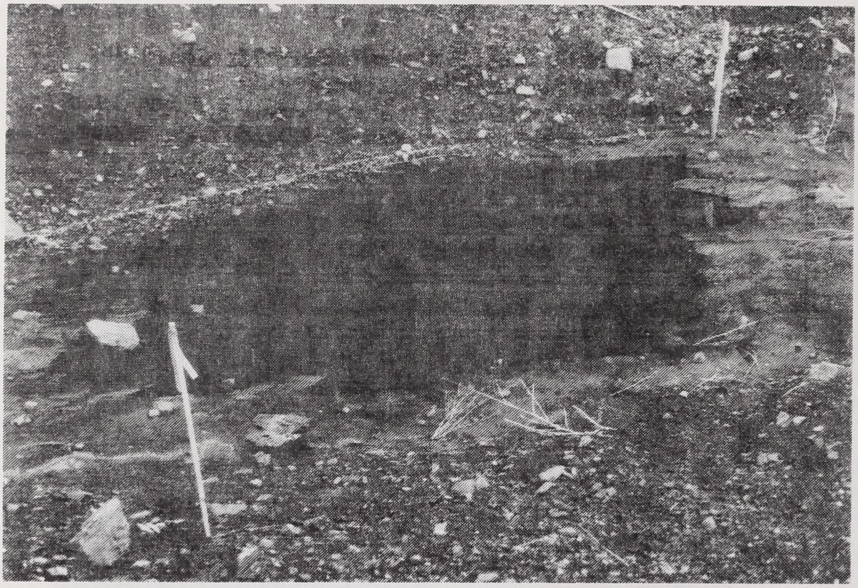

Figure 15. Deposition plot, base of slope 5, Tent Mountain

Figure 16. Plot 18, slope 5, Tent Mountain